MC13201

2.4 GHz Low Power Transceiver for the IEEE® 802.15.4 Standard

Reference Manual

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About This Book

This manual describes the Freescale MC13201. The MC13201 is a 2.4 GHz ISM band transceiver built for the IEEE® 802.15.4 Standard. The MC13201 transceiver can function as a standalone transceiver or when combined with a software package and an HCS08 MCU, they form the Freescale 802.15.4 Standard platform solution.

Audience

This manual is intended for system designers.

Organization

This document is organized into nine (9) chapters.

Chapter 1	**Introduction** — The MC13201 is Freescale's second-generation ZigBee™ transceiver. This transceiver is a low power, 2.4 GHz radio frequency transceiver that can be coupled with an 8-bit microcontroller.
Chapter 2	**Pins and Connections** — Describes device pinout and functionality.
Chapter 3	System Considerations — Describes system level considerations of the MC13201 modem.
Chapter 4	**Modem Register Descriptions** — Details how all control, reading of status, writing of data, and reading of data is done through the MC13201 SPI port
Chapter 5	**MC13201 Serial Peripheral Interface (SPI)** — Shows how the MC13201 modem and CPU communicate primarily through the onboard SPI command channel.
Chapter 6	**Modem Modes of Operation** — Describes the numerous MC13201 passive operational modes that allow for low-current operation as well as modes where the transceiver is active.
Chapter 7	**Modem Timer Information** — Describes how the MC13201 uses its internal Event Timer block to manage system timing.
Chapter 8	**Modem Interrupt Description** — Shows how interrupts provide a way for the MC13201 to inform the host microcontroller (MCU) of onboard events without requiring the MCU to constantly query MC13201 status.
Chapter 9	**Modem Miscellaneous Functions** — Describes how the MC13201 can be placed in one of two reset conditions either through hardware input M_RSTB or by writing to Reset Register 00.

Conventions

This document uses the following notational conventions:

- `Courier monospaced type indicate commands, command parameters, code examples, expressions, data types, and directives`
- *Italic type indicates replaceable command parameters*
- All source code examples are in C

Definitions, Acronyms, and Abbreviations

The following list defines the acronyms and abbreviations used in this document.

ACK	Acknowledgement Frame
API	Application Programming Interface
BB	Baseband
CCA	Clear Channel Assessment
CRC	Cyclical Redundancy Check
DCD	Differential Chip Decoding
DME	Device Management Entity
FCS	Frame Check Sequence
FFD	Full Function Device
FFD-C	Full Function Device Coordinator
FLI	Frame Length Indicator
GTS	Guaranteed Time Slot
HW	Hardware
IRQ	Interrupt Request
ISR	Interrupt Service Routine
LO	Local Oscillator
MAC	Medium Access Control
MCPS	MAC Common Part Sublayer
MCU	Microcontroller Unit
MLME	MAC Sublayer Management Entity
MSDU	MAC Service Data Unit
NWK	Network
PA	Power Amplifier
PAN	Personal Area Network
PANID	PAN Identification
PHY	PHYsical Layer
PIB	PAN Information Base

PPDU	PHY Protocol Data Unit
PSDU	PHY Service Data Unit
RF	Radio Frequency
RFD	Reduced Function Device
SAP	Service Access Point
SFD	Start of Frame Delimiter
SPI	Serial Peripheral Interface
SSCS	Service Specific Convergence Layer
SW	Software
VCO	Voltage Controlled Oscillator

Revision History

The following table summarizes revisions to this document since the previous release (Rev 1.0).

Revision History

Location	Revision
Chapter 4	Corrected error in section 4.28 and 4.33.

References

The following sources were referenced to produce this book:

[1] IEEE® 802.15.4 Standard

[2] Freescale MC13201 Data Sheet

Chapter 1
Introduction

The MC13201 is a short range, low power, 2.4 GHz Industrial, Scientific, and Medical (ISM) band transceivers. The MC13201 contains a complete packet data modem which is compliant with the 802.15.4 Standard PHY (Physical) layer. This allows the development of proprietary point-to-point and star networks based on the 802.15.4 packet structure and modulation format. For full 802.15.4 Standard compliance, the MC13201 and Freescale's 802.15.4 MAC software are required.

When combined with an appropriate microcontroller (MCU), the MC13201 provides a cost-effective solution for short-range data links and networks. Interface with the MCU is accomplished using a four wire serial peripheral interface (SPI) connection and an interrupt request output which allows for the use of a variety of processors. The software and processor can be scaled to fit applications ranging from simple point-to-point to star networks.

Applications include, but are not limited to, the following:

- Residential and commercial automation
  - Lighting control
  - Security
  - Access control
  - Heating, ventilation, air-conditioning (HVAC)
  - Automated meter reading
- Industrial Control
  - Asset tracking and monitoring
  - Homeland security
  - Process management
  - Environmental monitoring and control
  - HVAC
  - Automated meter reading (AMR)
- Health Care
  - Patient monitoring
  - Fitness monitoring

The transceiver includes a low noise amplifier, 1mW nominal output power, PA with internal voltage controlled oscillator (VCO), integrated transmit/receive switch, on-board power supply regulation, and full spread-spectrum encoding and decoding. The device supports 250 kbps Offset-Quadrature Phase Shift Keying (O-QPSK) data in 2.0 MHz channels with 5.0 MHz channel spacing per the 802.15.4 Standard.

The SPI port and interrupt request output are used for receive (RX) and transmit (TX) data transfer and control.

1.1 Features

- Power supply range: 2.0 to 3.4 V
- Operates on one of 16 selectable channels in the 2.4 GHz ISM band
- -1 to 0 dBm nominal output power, programmable from -27 dBm to +3 dBm typical
- Buffered transmit and receive data packets for simplified use with low cost MCUs
- Supports 250 kbps O-QPSK data in 5.0 MHz channels and full spread-spectrum encode and decode (compatible with 802.15.4 Standard)
- Three power down modes for power conservation:
    - 1 µA Typical Off current
    - 2.3 µA Typical Hibernate current
    - 35 µA Typical Doze current
- Receive sensitivity of <-91 dBm (typical) at 1% PER, 20-byte packet, much better than the IEEE 802.15.4 Standard of -85 dBm
- Integrated transmit/receive switch
- Dual PA output pairs which can be programmed for full differential single port or dual port operation that supports an external LNA and/or PA
- Two internal timer comparators available to reduce MCU resource requirements
- Programmable frequency clock output for use by MCU
- Onboard trim capability for 16 MHz crystal reference oscillator eliminates the need for external variable capacitors and allows for automated production frequency calibration.
- Seven general purpose input/output (GPIO) signals
- Operating temperature range: -40°C to 85°C
- Small form factor QFN-32 Package
    - RoHS compliant
    - Meets moisture sensitivity level (MSL) 3
    - 260°C peak reflow temperature
    - Meets lead-free requirements

1.2 Software Support

Freescale provides a software package (source available) called the Simple MAC (SMAC). It is custom MAC that allows proprietary solutions with the following features:

- Small memory footprint (about 3 kbytes typical))
- Supports point-to-point and star network configurations
- Proprietary networks
- Source code and application examples provided

NOTE

If 802.15.4 Standard-compliant MAC applications are required (including ZigBee), the MC13202 or MC13203 device should be used.

1.3 Block Diagrams

Figure 1-1 shows a simplified block diagram of the MC13201 which is an 802.15.4 Standard compatible transceiver that provides the functions required in the physical layer (PHY) specification.

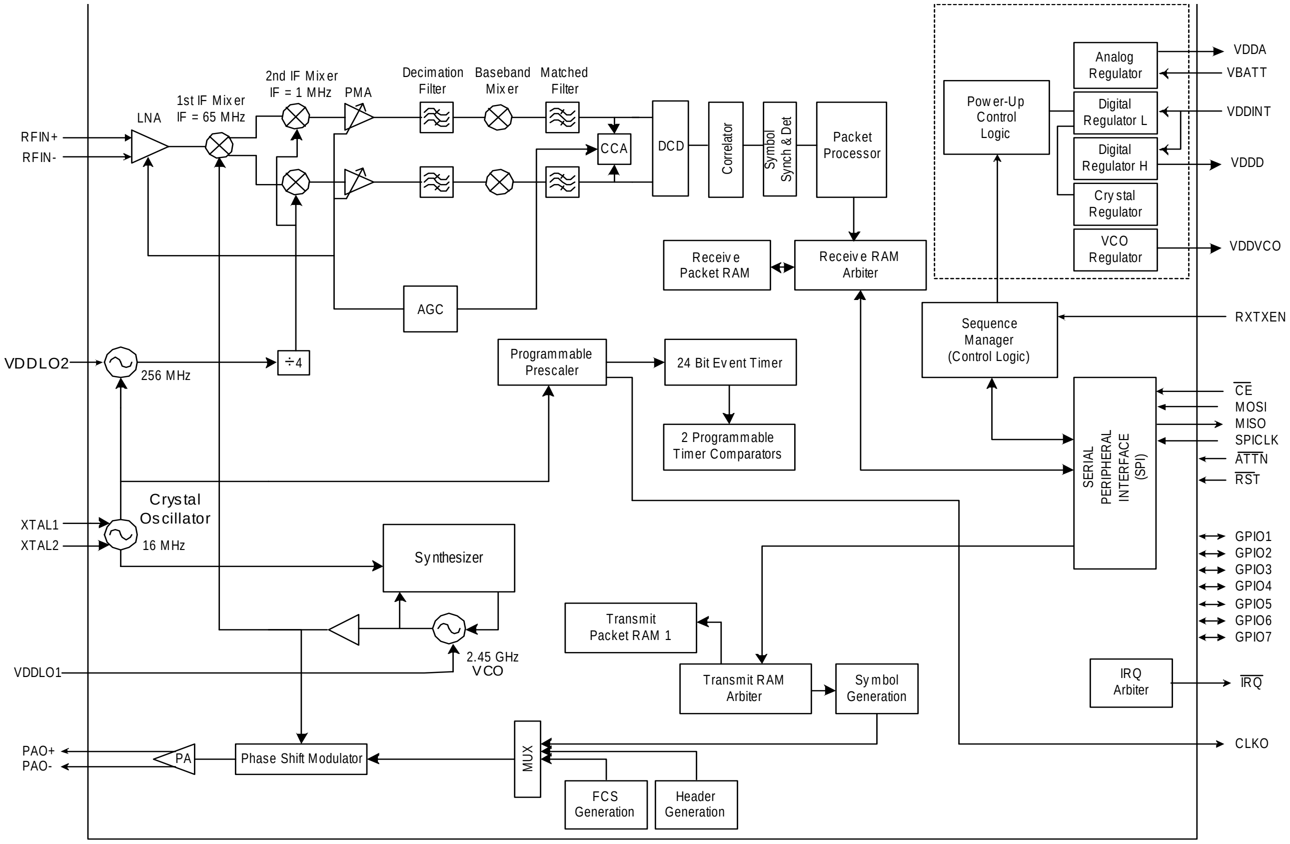


Figure 1-1. MC13201 Simplified Block Diagram

Figure 1-2 shows the basic system block diagram for the MC13201 in an application. Interface with the transceiver is accomplished through a 4-wire SPI port and interrupt request line. The media access control (MAC), drivers, and network and application software (as required) reside on the host processor. The host can vary from a simple 8-bit device up to a sophisticated 32-bit processor depending on application requirements.

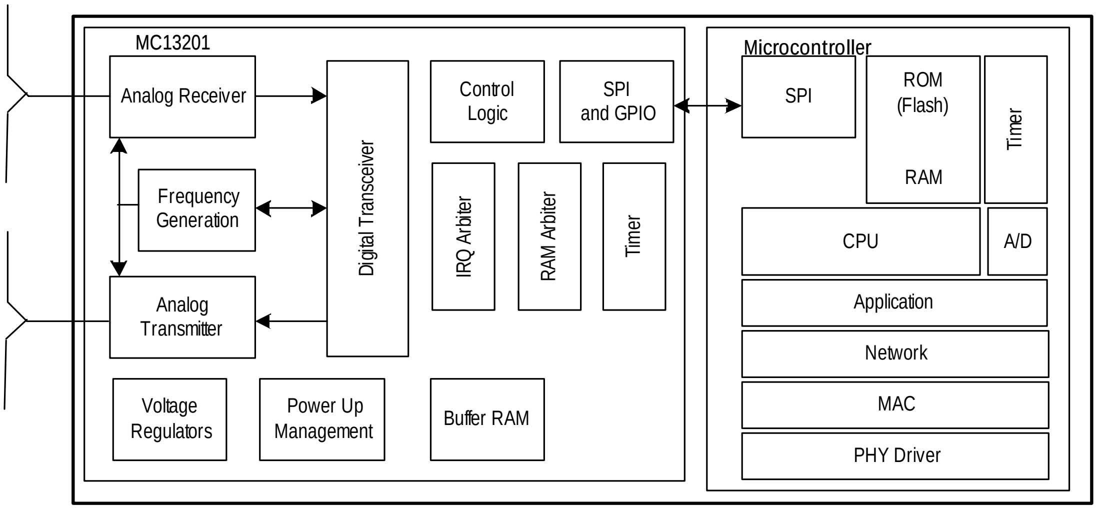


Figure 1-2. System Level Block Diagram

1.4 Data Transfer Modes

The MC13201 has a data transfer mode called Packet Mode where data is buffered in on-chip Packet RAMs. There is a TX Packet RAM and an RX Packet RAM, each of which are 64 locations by 16 bits wide.

1.5 Packet Structure

Figure 1-3 shows the packet structure of the MC13201. Payloads of up to 125 bytes are supported. The MC13201 adds a four-byte preamble, a one-byte Start of Frame Delimiter (SFD), and a one-byte Frame Length Indicator (FLI) before the data. A Frame Check Sequence (FCS) is calculated and appended to the end of the data.

4 bytes	1 byte	1 byte	125 bytes maximum	2 bytes
Preamble	SFD	FLI	Payload Data	FCS

Figure 1-3. MC13201 Packet Structure

1.6 Receive Path Description

In the receive signal path, the RF input is converted to low IF In-phase and Quadrature (I & Q) signals through two down-conversion stages. A Clear Channel Assessment (CCA) can be performed based upon the baseband energy integrated over a specific time interval. The digital back end performs Differential Chip Detection (DCD), the correlator “de-spreads” the Direct Sequence Spread Spectrum (DSSS) Offset QPSK (O-QPSK) signal, determines the symbols and packets, and detects the data.

The preamble, SFD, and FLI are parsed and used to detect the payload data and FCS which are stored in RAM. A two-byte FCS is calculated on the received data and compared to the FCS value appended to the transmitted data, generating a Cyclical Redundancy Check (CRC) result. Link Quality is measured over a 64 μs period after the packet preamble and stored in RAM.

If the MC13201 uses a packet mode where the data is processed as an entire packet. The MCU is notified that an entire packet has been received via an interrupt.

1.7 Transmit Path Description

For the transmit path, the TX data that was previously stored in RAM are retrieved, formed into packets per the 802.15.4 PHY, spread, and then up converted to the transmit frequency.

Because the MC13201 uses a packet mode, data are processed as an entire packet. The data is first loaded into the TX buffer. The MCU then requests that the MC13201 transmit the data. The MCU is notified via an interrupt when the whole packet has successfully been transmitted.

Chapter 2
MC13201 Pins and Connections

2.1 Device Pin Assignment

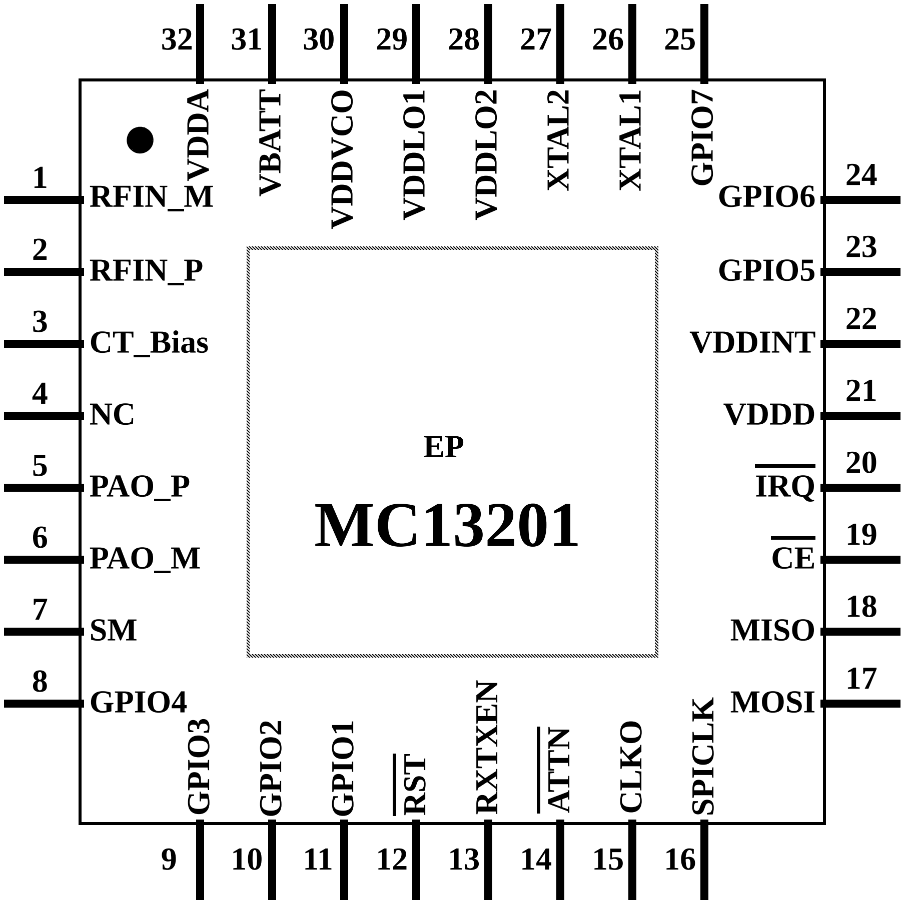


Figure 2-1. MC13201 Pinout

2.2 Pin Definitions

Table 2-1. Pin Function Description

Pin #	Pin Name	Type	Description	Functionality
1	RFIN_M	RF Input	RF input/output negative.	When used with internal T/R switch, this is a bi-directional RF port for the internal LNA and PA
2	RFIN_P	RF Input	RF input/output positive.	When used with internal T/R switch, this is a bi-directional RF port for the internal LNA and PA
3	CT_Bias	Control voltage	Bias voltage/control signal for external RF components	When used with internal T/R switch, provides RX ground reference and TX VDDA reference for use with external balun. Can also be used as a control signal for external LNA, PA, or T/R switch.
4	NC		Tie to Ground.	
5	PAO_P	RF Output /DC Input	RF Power Amplifier Output Positive.	Open drain. Connect to VDDA through a bias network when used with an external balun. Not used when internal T/R switch is used.
6	PAO_M	RF Output/DC Input	RF Power Amplifier Output Negative.	Open drain. Connect to VDDA through a bias network when used with an external balun. Not used when internal T/R switch is used.
7	SM	Input	Test mode pin.	Must be grounded for normal operation.
8	GPIO4	Digital Input/ Output	General Purpose Input/Output 4.	
9	GPIO3	Digital Input/ Output	General Purpose Input/Output 3.	
10	GPIO2	Digital Input/ Output	General Purpose Input/Output 2. When gpio_alt_en, Register 9, Bit 7 = 1, GPIO2 functions as a “CRC Valid” indicator.	
11	GPIO1	Digital Input/ Output	General Purpose Input/Output 1. When gpio_alt_en, Register 9, Bit 7 = 1, GPIO1 functions as an “Out of Idle” indicator.	
12	$\overline{\text{RST}}$	Digital Input	Active Low Reset. While held low, the IC is in Off Mode and all internal information is lost from RAM and SPI registers. When high, IC goes to IDLE Mode, with SPI in default state.	
13	RXTXEN	Digital Input	Active High. Low to high transition initiates RX or TX sequence depending on SPI setting. Should be taken high after SPI programming to start RX or TX sequence and should be held high through the sequence. After sequence is complete, return RXTXEN to low. When held low, forces Idle Mode.	

Table 2-1. Pin Function Description (continued)

Pin #	Pin Name	Type	Description	Functionality
14	$\overline{\text{ATTN}}$	Digital Input	Active Low Attention. Transitions IC from either Hibernate or Doze Modes to Idle.	
15	CLKO	Digital Output	Clock output to host MCU. Programmable frequencies of: 16 MHz, 8 MHz, 4 MHz, 2 MHz, 1 MHz, 62.5 kHz, 32.786+ kHz (default), and 16.393+ kHz.	
16	SPICLK	Digital Clock Input	External clock input for the SPI interface.	
17	MOSI	Digital Input	Master Out/Slave In. Dedicated SPI data input.	
18	MISO	Digital Output	Master In/Slave Out. Dedicated SPI data output.	
19	$\overline{\text{CE}}$	Digital Input	Active Low Chip Enable. Enables SPI transfers.	
20	$\overline{\text{IRQ}}$	Digital Output	Active Low Interrupt Request.	Open drain device. Programmable 40 kΩ internal pull-up. Interrupt can be serviced every 6 µs with <20 pF load. Optional external pull-up must be >4 kΩ.
21	VDDD	Power Output	Digital regulated supply bypass.	Decouple to ground.
22	VDDINT	Power Input	Digital interface supply & digital regulator input. Connect to Battery.	2.0 to 3.4 V. Decouple to ground.
23	GPIO5	Digital Input/Output	General Purpose Input/Output 5.	
24	GPIO6	Digital Input/Output	General Purpose Input/Output 6.	
25	GPIO7	Digital Input/Output	General Purpose Input/Output 7.	
26	XTAL1	Input	Crystal Reference oscillator input.	Connect to 16 MHz crystal and load capacitor.
27	XTAL2	Input/Output	Crystal Reference oscillator output **Note:** Do not load this pin by using it as a 16 MHz source. Measure 16 MHz output at Pin 15, CLKO, programmed for 16 MHz.	Connect to 16 MHz crystal and load capacitor.
28	VDDLO2	Power Input	LO2 VDD supply. Connect to VDDA externally.	
29	VDDLO1	Power Input	LO1 VDD supply. Connect to VDDA externally.	
30	VDDVCO	Power Output	VCO regulated supply bypass.	Decouple to ground.

Table 2-1. Pin Function Description (continued)

Pin #	Pin Name	Type	Description	Functionality
31	VBATT	Power Input	Analog voltage regulators Input. Connect to Battery.	Decouple to ground.
32	VDDA	Power Output	Analog regulated supply Output. Connect to directly VDDLO1 and VDDLO2 externally and to PAO± through a bias network. **Note**: Do not use this pin to supply circuitry external to the chip.	Decouple to ground.
EP	Ground		External paddle / flag ground.	Connect to ground.

Chapter 3
System Considerations

3.1 Introduction

The MC13201 is an 802.15.4 Standard transceiver in a single QFN package which can provide solutions to proprietary point-to-point links and nets with an 802.15.4 Standard-compatible physical layer. All control to the modem is achieved through the common SPI bus, the MCU interrupt request, and several MCU GPIO lines. Primary interface with the modem is through the SPI command structure that allows reading/writing modem registers and provides initialization of parameters, reading of status, and control of modem operation. The modem can ask for real time response through the interrupt request signal.

This chapter presents information regarding operation of the modem from a system level. The areas considered here are also covered in greater detail in the following sections of the book. The book is organized such that the first three chapters present the top-level view of the MC13201 device and the following chapters present individual functions with detailed descriptions.

3.2 Power Connections

The MC13201 power connections are listed in Table 3-1.

Table 3-1. Power Pin Descriptions

Pin #	Pin Name	Type	Description	Functionality
22	VDDINT	Power Input	Digital interface supply & digital regulator input. Connect to Battery.	2.0 to 3.4 V. Decouple to ground.
21	VDDD	Power Output	Regulated output supply voltage	Decouple to ground.
31	VBATT	Power Input	Voltage regulators' input. Connect to Battery	Decouple to ground.
32	VDDA	Power Output	Analog regulated supply output	Decouple to ground. Connect to directly VDDLO1 and VDDLO2 externally.
30	VDDVCO	Power Output	Modem VCO regulated supply bypass	Decouple to ground.
29	VDDLO1	Power Input	Modem LO1 VDD supply	Connect to VDDA externally.
28	VDDLO2	Power Input	Modem LO2 VDD supply	Connect to VDDA externally.
EP	VSS	Power input	External package flag. Common VSS	Connect to ground.

When designing power to the device, the following points need to be considered:

- The QFN package has a single common EP ground flag (VSS)
- There are two primary power inputs which include VBATT for modem power and VDDINT for digital interface power
- For logic level compatibility between the modem and the system CPU, VBATT, and VDDINT must be connected with the CPU to a common source supply of 2.0 - 3.4 VDC
- Input VBATT feeds the common supply to the analog and digital circuitry regulators. The analog regulator output VDDA is provided both for bypassing and to supply VDDLO1 and VDDLO2 which are the power rails for the local oscillators
- Output VDDVCO is provided to allow separate bypass of the modem radio VCO regulated supply

Power supply connections are shown in Figure 3-1.

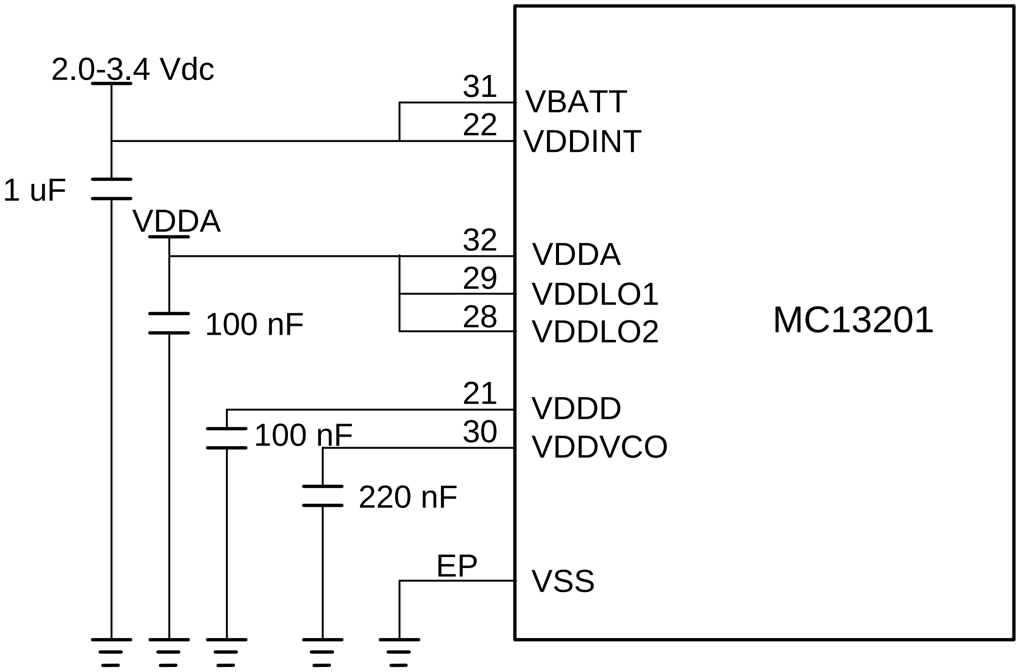


Figure 3-1. MC13201 Power Supply Connections

NOTE

There are separate bypass capacitors on VDDA, VDDD, and VDDVCO. In some RF circuitry configurations, VDDA may also need to be DC-coupled to the radio PA outputs.

3.3 Test Pin SM

Input SM is a test pin that must be grounded for normal operation.

3.4 Reset Usage

The modem active low reset input $\overline{\text{RST}}$ is recommended to be driven from an MCU GPIO pin. In the interest of lowest power, there is no pull-up resistor on input $\overline{\text{RST}}$. An MCU GPIO programmed as an output typically also has a software controlled pull-up resistor. However, it would normally not be used because the modem can be held in hardware reset by the MCU for extended periods of time, and having no resistor makes for lowest power applications.

From a power-on or “cold start” condition, the MCU GPIO normally initiates as a high-impedance input with the internal pull-up disabled. As a result, the modem reset input will be floating and the modem will not be held in reset. As part of the MCU initialization, GPIO must be programmed as an output and then driven low to reset the modem. The $\overline{\text{RST}}$ input is asynchronous and needs to be held low for only a short period.

In the reset condition, the modem is totally powered down and no clocks are available. After $\overline{\text{RST}}$ is released, the modem will power up, initialize, and go to its idle condition within 10 - 25 milliseconds, and in turn, this causes an ATTN interrupt request and allows CLKO to start toggling at 32.768+ kHz (both of which are default conditions). The ATTN hardware interrupt request is normally caused by asserting modem signal $\overline{\text{ATTN}}$, however, coming out of reset the ATTN status bit is set and the ATTN interrupt request mask is set.

Once the interrupt request is seen by the MCU, the MCU can assume the modem is alive and ready for programming via the SPI bus. Modem reset operation and control is detailed in Chapter 9, “Miscellaneous Functions.

3.5 MC13201 Interface to MCU

The modem interacts with the host MCU through its SPI interface, interrupt request, and several status and control signals.

3.5.1 SPI Command Channel

Primary interface with the modem is through the SPI command structure that allows reading/writing modem registers and provides initialization of parameters, reading of status, and control of modem operation. The modem is a slave only and the MCU SPI must be programmed and used as a master only. Further, the SPI performance is limited by the modem constraints of 8 MHz maximum SPI clock frequency, and use of the MCU SPI must be programmed to meet the modem SPI protocol. The SPI bus connections for a Freescale 9S08 typically are:

- MCU MOSI1 output drives modem MOSI
- Modem MISO output drives MCU MISO1
- MCU SPSCK1 output drives modem SPICLK
- MCU $\overline{\text{SS1}}$ output drives modem $\overline{\text{CE}}$

The use and programming of the SPI command channel is described in Chapter 5, “Serial Peripheral Interface (SPI).

3.5.2 Interrupt Request to MCU

The modem interrupt request $\overline{\text{IRQ}}$ is an active low open drain output that is asserted when an interrupt request is pending. The signal is released to high by reading the modem IRQ_Status register via a SPI transaction. $\overline{\text{IRQ}}$ has a programmable pull-up resistor (default is active) and the output also can be programmed for drive strength. $\overline{\text{IRQ}}$ is covered in detail in Section 8.1.2, “Output Pin IRQ, and Section 8.1, “Interrupts.

The $\overline{\text{IRQ}}$ maximum drive strength is suggested as this will give fastest performance for the interrupt fall time.

3.5.3 Modem Control Signals

The modem requires two additional input control signals that are typically controlled by the MCU GPIO:

- $\overline{\text{ATTN}}$ - is an active low attention signal that is used wake the modem from Hibernate or Doze Mode. An MCU GPIO must be programmed as an output and controls this input
- RXTXEN - is an active high input used to enable transmit, receive, and CCA operations in the modem. An MCU usually is programmed as an output and controls this input

3.5.4 Modem Status Signals

The modem has two programmable signals that can provide real-time status to the MCU:

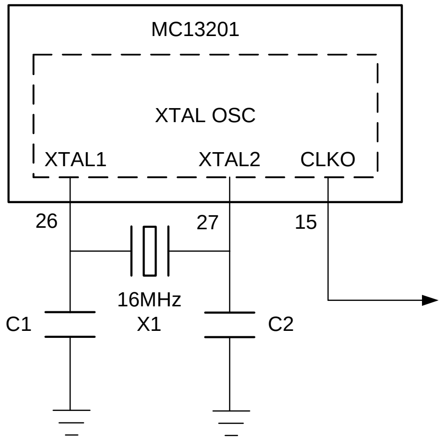
- GPIO1/Out_of_Idle output — The modem GPIO1 signal can optionally be programmed as an “out-of-idle” indicator for monitoring RX, TX, or CCA operation. An MCU GPIO must be programmed as an input to monitor this signal. The modem GPIO1 signal can also be used as a general purpose IO
- GPIO2/CRC_Valid output — The modem GPIO2 signal can optionally be programmed as an “CRC valid” indicator for monitoring an RX operation. An MCU GPIO must be programmed as an input to monitor this signal. The modem GPIO2 signal can also be used as a general purpose IO

3.6 System Oscillator and Clock Considerations

3.6.1 Modem Crystal Oscillator

The modem oscillator source must always be present and an external crystal is used to implement the oscillator. The source frequency must be 16 MHz with a total accuracy of +/- 40 ppm or greater as required by the 802.15.4 Standard. A detailed discussion of required crystal characteristics is in Section 9.3.1, “Crystal Requirements.

In Figure 3-2 crystal X1 and capacitors C1 and C2 form the modem crystal oscillator circuit. An onboard feedback resistor of approximately 1 MOhm (not shown) between input XTAL1 and output XTAL2 provides DC biasing for the oscillator buffer. An important parameter for the 16 MHz crystal X1 is a load capacitance of <9 pF. The oscillator needs to see a balanced load capacitance at each terminal of about 18pF. As a result, the sum of the stray capacitance of the PCB, device pin (XTAL1 or XTAL2), and load capacitor (C1 or C2) at each terminal must equal about 18 pF. C1 and C2 are typically values of 6-9 pF. Higher values can load the crystal buffer and cause oscillator start-up problems.



If the MCU has an internal startup clock, the external MCU clock source can be driven by the CLKO output of the modem.

Figure 3-2. MC13201 Oscillator and External Clock Connections

As described in Section 9.3.2, "Crystal Trim Operation, the MC13201 crystal oscillator frequency can be trimmed by programming modem CLKO_Ctl Register 0A, Bits 15-8 (xtal_trim[7:0]). The trimming procedure varies the frequency by a few hertz per step, depending on the type of crystal. As xtal_trim[7:0] is increased, the frequency is decreased. This feature is useful for factory calibration of the crystal frequency to set the accuracy for the radio as required by the 802.15.4 Standard.

3.6.2 System Clock Configurations

Because of the multiple clock configurations in an MCU and the CLKO output from the modem, there are a number of variations for system clock configurations. Key considerations for any system clock configuration are:

- The modem 16 MHz source (typically the crystal oscillator) must always be present. The crystal has special requirements and the reference frequency must meet 802.15.4 Standard requirements
- Battery-operated application requirements for low power can impact the choices for MCU clock source
- The system clock configuration can impact system initialization procedures.
- Software requirements can impact MCU processor and bus speed. The user must be aware of the performance requirements for the MCU. In the Freescale software running on the 689S08, the CPU clock is always 2X the internal bus speed, and the SMAC application software requires an 8 MHZ bus clock

3.6.3 Single System Crystal with CLKO driving MCU EXTAL input

The single crystal (modem crystal) with CLKO driving the MCU external clock input is a common configuration for low cost and excellent frequency accuracy. The CLKO frequency is programmable from 16.393+ kHz to 16 Mhz and drives the MCU external source.

NOTE

For this system option to be usable, the system MCU must have an alternative (typically onboard) start-up clock.

In this configuration, clock start-up from a reset condition involves:

- MCU reset is released and MCU starts on an internal clock
- Initialization software must reset and then release reset to the modem (MCU still running on start-up clock)
- Wait for modem start-up interrupt request (approximately 10 - 25 msec). CLKO default is active with a frequency of 32.786+ kHz
- Program CLKO to a different frequency (if desired)
- Wait for the CLKO source to lock, and then switch MCU clock to external source

Additional considerations for this mode of operation include:

- If the modem is forced to the Off condition and CLKO is killed, there is a 10 - 25 msec wait for the modem CLKO to start from the Off condition after $\overline{\text{RST}}$ is released
- If the MCU puts the modem into Doze mode, keeping the CLKO alive is a higher power, but available option
- If an accurate period is required for longer time delays (such as a beacon period), keeping CLKO alive for very long periods is an option, but would be a higher power option typically than using a separate crystal for the MCU

3.7 GPIO Characteristics

The modem GPIO hardware consists of 7 signals total (GPIO1-GPIO7). Immediately after reset, all the GPIO pins are configured as high-impedance general-purpose inputs. There are no internal pullup devices on these pins.

NOTE

To avoid extra current drain from floating input pins, the power up initialization routine in the application program should change the direction of unused pins to outputs (programmed low) so the pins do not float. Outputs programmed low is the preferred option for lowest power.

As described in Section 3.5.4, “Modem Status Signals, GPIO1 and GPIO2 can be programmed as special status signals. The alternate functionality of the GPIO1-GPIO2 are controlled by the applications program and use of these pins is described in Chapter 9, “Miscellaneous Functions.

The functionality of the modem GPIO is controlled by programming of the modem SPI registers via the SPI interface. For information about controlling all these pins as general-purpose I/O pins, see Chapter 9, “Miscellaneous Functions.

3.8 MC13201 Digital Signal Properties Summary

Table 3-2 summarizes digital I/O pin characteristics. These characteristics are determined by the way the common pin interfaces are hard-wired to internal circuits.

Table 3-2. MC13201 Digital Signal Properties

Pin Name	Dir	High Current Pin	Output Slew [1]	Pull-Up[2]	Comments
$\overline{\text{IRQ}}$	O	N	SWC	SWC	Open drain
XTAL1	I	—	—	N	
XTAL2	O	N	N	N	
$\overline{\text{ATTN}}$	I	—	—	N	
RXTXEN	I	—	—	N	
$\overline{\text{RST}}$	I	—	—	N	
CLKO	O	N	SWC	N	
SPICLK	I	—	—	N	
MOSI	I	—	—	N	
MISO	O	N	SWC	N	Off state is SWC
$\overline{\text{CE}}$	I	—	—	N	
GPIO1/Out_of_Idle	I/O	N	SWC	N	Programmable status bit
GPIO2/CRC_Valid	I/O	N	SWC	N	Programmable status bit
GPIO3	I/O	N	SWC	N	
GPIO4	I/O	N	SWC	N	
GPIO5	I/O	N	SWC	N	
GPIO6	I/O	N	SWC	N	
GPIO7	I/O	N	SWC	N	

[1] SWC is software controlled slew rate, the register is associated with the respective port.

[2] SWC is software controlled pull-up resistor, the register is associated with the respective port.

3.9 Transceiver RF Configurations and External Connections

The MC13201 radio has features that allow for a flexible as well as low cost RF interface:

- Programmable output power — -1dBm to 0 dBm nominal output power, programmable from -27 dBm to +3 dBm typical
- <-91 dBm (typical) receive sensitivity — At 1% PER, 20-byte packet (well above 802.15.4 Standard of -85 dBm)
- Optional integrated transmit/receive (T/R) switch for low cost operation — With internal PAs and LNA, the internal T/R switch allows a minimal part count radio interface using only a single balun to interface to a single-ended antenna
- Maximum flexibility — There are full differential RF I/O pins for use with the internal T/R switch. Optionally, these pins become the RF_IN signals and a separate set of full differential PA outputs are also provided. Separate inputs and outputs allow for a variety of RF configurations including external LNA and PA for increased range
- CT_Bias Output — The CT_Bias signal provides a switched bias reference for use with the internal T/R switch, and alternatively can be programmed as an antenna switch signal for use with an external antenna switch
- Onboard trim capability for 16 MHz crystal reference oscillator — The 802.15.4 Standard puts a +/- 40 ppm requirement on the carrier frequency. The onboard trim capability of the modem crystal oscillator eliminates need for external variable capacitors and allows for automated production frequency calibration. Also tighter tolerance can produce greater receive sensitivity

3.9.1 RF Interface Pins

Figure 3-3 shows the RF interface pins and the associated analog blocks. Notice that separate PA blocks are associated with RFIN_x and PAO_x signal pairs. The RF interface allows both single port differential operation and dual port differential operation.

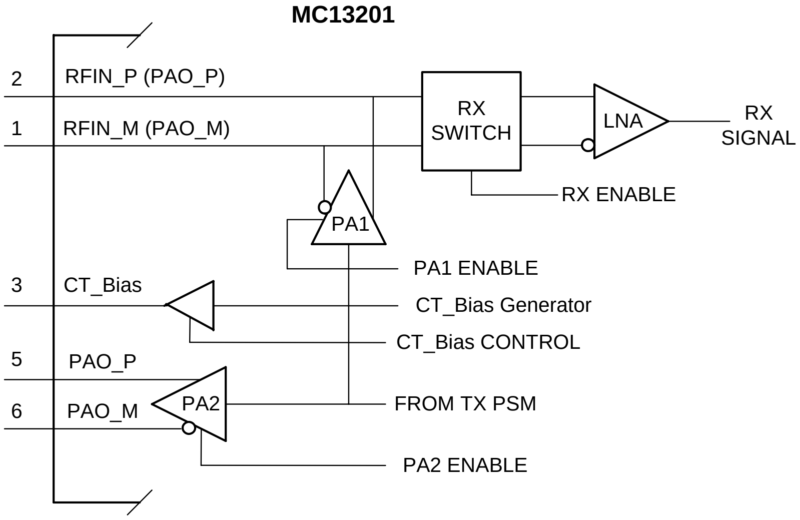


Figure 3-3. RF Interface Pins

3.9.1.1 Single Port Operation

The integrated RF switch allows users to operate in a single port configuration. In Single Port Mode, an internal RX switch and separate PA are used and pins RFIN_P (PAO_P) and RFIN_M (PAO_M) become bidirectional and connect both for TX and RX. When receiving, the RX switch is enabled to the internal LNA and the TX PA1 is disabled. When transmitting, the RX switch is disabled (isolating the LNA) and TX PA1 is enabled. The optional CT_Bias pin provides a reference or bias voltage which is at VDDA for transmit and is at ground for receive. This signal can be used to provide the proper bias voltage to a balun that converts a single-ended antenna to the differential interface required by the device.

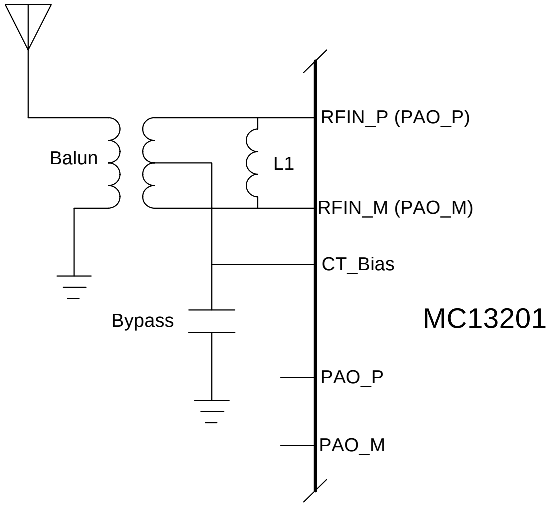


Figure 3-4. Single Port RF Operation with a Balun

Figure 3-4 shows a single port example with a balun. The CT_Bias is connected to the balun center-tap providing the proper DC bias voltage to the balun depending on RX or TX.

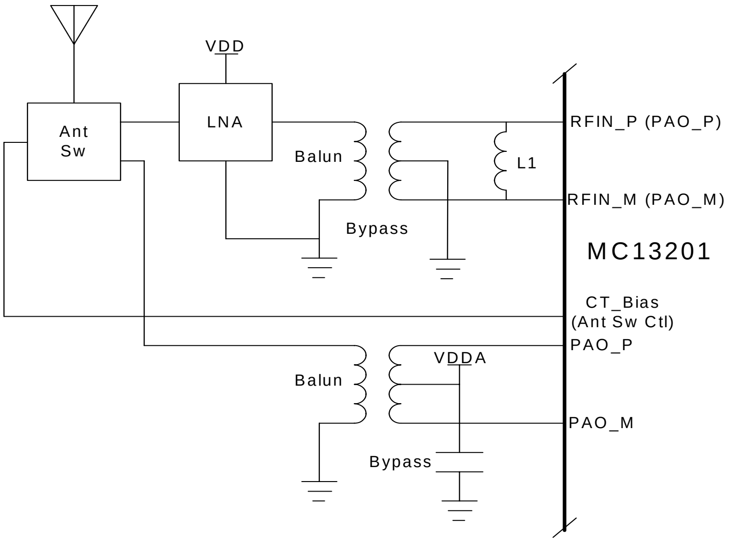
3.9.1.2 Dual Port Operation

A second set of pins designated PAO_P and PAO_N allow operation in a dual port configuration. There are separate paths for transmit and receive with the optional CT_Bias pin providing a signal that indicates if the radio is in TX or RX Mode which then can be used to drive an external low noise amplifier or power amplifier.

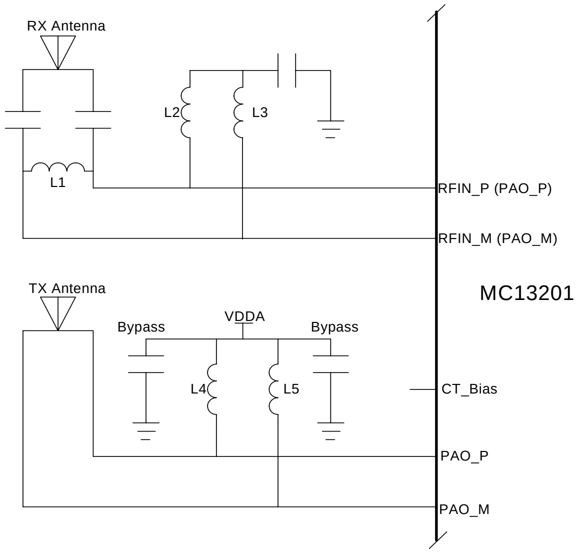
In dual port operation, the RFIN_P and RFIN_N are inputs only, the internal RX switch to the LNA is enabled to receive, and the associated TX PA1 stays disabled. Pins PAO_P and PAO_N become the differential output pins and the associated TX PA2 is enabled for transmit.

Figure 3-5 shows two dual port configurations. First is a single antenna configuration with an external low noise amplifier (LNA) for greater range. An external antenna switch is used to multiplex the antenna between receive and transmit. An LNA is in the receive path to add gain for greater receive sensitivity. Two external baluns are required to convert the single-ended antenna switch signals to the differential signals required by the radio. Separate RFIN and PAO signals are provided for connection with the baluns, and the CT_bias signal is programmed to provide the external switch control. The polarity of the external switch control is selectable.

Figure 3-5 also shows a dual antenna configuration where there is a RX antenna and a TX antenna. For the receive side, the RX antenna is ac-coupled to the differential RFIN inputs and these capacitors along with inductor L1 form a matching network. Inductors L2 and L3 are ac-coupled to ground to form a frequency trap. For the transmit side, the TX antenna is connected to the differential PAO outputs, and inductors L4 and L5 provide DC-biasing to VDDA but are ac isolated. CT_Bias is not required or used.



Using External Antenna Switch with LNA



Using Dual Antenna

Figure 3-5. Dual Port RF Configuration Examples

3.9.2 Controlling RF Modes of Operation

Use of the RF interface pins and RF modes of operation are controlled through several bits of Control_B Register 07. Figure 3-6 shows the model for Register 07 with the RF interface control bits highlighted.

Register 07 0x07

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tmr_load	**ct_bias_en**	**ct_bias_inv**	**RF_switch_mode**	miso_hiz_en		clko_doze_en		tx_done_mask	rx_done_mask	use_strm_mode				hib_en	doze_en
TYPE	r/w	r/w	r/w	r/w	r/w		r/w		r/w	r/w	r/w				r/w	r/w
RESET	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0

0x0C00

Figure 3-6. Modem Control_B Register 07 Model

The RF interface control bits include:

- RF_switch_mode (Bit 12) - This bit selects Dual Port Mode versus Single Port Mode
  - The default condition (Bit 12 = 0) is Dual Port Mode where the RF inputs are RFIN_M and RFIN_P and the RF outputs are PAO_M and PAO_P and operation is as described in Section 3.9.1.2, "Dual Port Operation. The use of CT_Bias pin in Dual Port Mode in controlled by Bit 13 and Bit 12
  - When Bit = 1, the Single Port Mode is selected where RFIN_M (PAO_M) and RFIN_P (PAO_P) become bidirectional pins and operation is as described in Section 3.9.1.1, "Single Port Operation. The use of CT_Bias pin in Single Port Mode in controlled by Bit 14 and operation of the radio
- ct_bias_en (Bit 14) - This bit is the enable for the CT_Bias output. When Bit 14 = 0 (default), the CT_Bias is disabled and stays in a Hi-Z or tri-stated condition. When Bit 14 = 1 the CT_Bias output is active and its state is controlled by the selected mode (Bit 12), ct_bias_inv, and operation of the radio
- ct_bias_inv (Bit 13) - This bit only affects the state of CT_Bias when Dual Port Mode is selected and CT_Bias is active. The CT_Bias changes state in Dual Port Mode based on the TX or RX state of the radio. The ct_bias_inv bit causes the sense of the active state to change or invert based on Bit 13's setting. In this manner the user can select the CT_Bias as a control signal for external components and make the control signal active high or active low

Table 3-3 summarizes the operation of the RF interface control bits.

Table 3-3. RF Interface Control Bits

Bit	Designation	Default	Operation
14	ct_bias_en	0	1 = CT_Bias enabled. Output state is defined by Table 3-4. 0 = CT_Bias disabled. Output state is tri-stated.
13	ct_bias_inv	0	The output state of CT_Bias under varying conditions is defined in Table 3-4. This bit only has effect for dual port operation. 1 = CT_Bias inverted. 0 = CT_Bias not inverted
12	RF_switch_mode	0	1= Single Port Mode selected where RF switch is active and RFIN_M and RFIN_P and bidirectional signals. 0 = Dual Port Mode selected where RFIN_M and RFIN_P are inputs only and PAO_P and PAO_N are separate outputs. (This is default operation).

3.9.3 RF Control Output CT_Bias

CT_Bias is a useful signal for interface with external RF components. It must be enabled via the ct_bias_en control bit, and then its state is determined first by the selected RF mode and then by the active state of the radio, i.e., whether a TX or RX operation is active:

- Single Port Operation — In this mode, the CT_Bias can be used to establish the proper DC bias voltage to a balun depending on the RX state versus TX state as described in Section 3.9.1.1, “Single Port Operation. Note that in single port operation, the ct_bias_inv has no effect and CT_Bias is at VDDA for TX and is at ground for RX
- Dual Port Operation — In this mode, the CT_Bias can be used as a control signal to enable an LNA or to determine the direction of an antenna switch as described in Section 3.9.1.2, “Dual Port Operation. In dual port operation ct_bias_inv is used to control the sense of the output control, i.e., CT_Bias can be active high or active low for TX and vice-versa for RX

Table 3-4 defines the CT_Bias output state depending on control bits and operation mode of the modem. Note that the output state is also defined for the modem low power states of Idle, Hibernate, and Doze as well as RX and TX operation.

Table 3-4. CT_Bias Output vs. Register Settings

Mode	CT_Bias_en	RF_switch_mode	CT_Bias_inv	CT_Bias
RX	1	1	0	0
RX	1	1	1	0
RX	1	0	0	0
RX	0	X	X	Hi-Z
RX	1	1	0	1
TX	1	1	0	1
TX	1	1	1	1
TX	1	0	0	1

Table 3-4. CT_Bias Output vs. Register Settings (continued)

Mode	CT_Bias_en	RF_switch_mode	CT_Bias_inv	CT_Bias
TX	1	0	1	0
TX	0	X	X	Hi-Z
Idle	1	X	X	0
Idle	0	X	X	Hi-Z
Doze	1	X	X	0
Doze	0	X	X	Hi-Z
Hibernate	1	X	X	0 (Low-Z)
Hibernate	0	X	X	Hi-Z
Off	X	X	X	Unknown

3.10 Low Power Considerations

Many ZigBee and/or 802.15.4 Standard applications such as sensor End Devices are required to be battery operated. As expected, long battery life is highly desirable and is very dependent on application parameters. Over-the-air operation uses RX, TX, and CCA modes, where power is highest. As a result, the time between radio operations should be kept at the longest possible period that the application will allow.

When designing low power operation of the MC13201 consider:

- The modem has several low power options
- The modem is entirely controlled by the MCU; the low power options/combinations will be determined by MCU programming
- The power down control of the modem must be maintained by the MCU in the MCU's power down configuration

Lowest power in a system is more than just putting the modem and/or the MCU in a low power mode. The relationship between the functions, the timing between them, and clock management must all be considered. The duty cycle between active operations is also very important as it can impact whether sleep operation or active operation will have the biggest impact over an extended time period.

3.10.1 Modem Low Power States

Table 3-5 lists the modem low power states and the modes are covered in detail in Chapter 6, "Modes of Operation. There are three low power modes available:

- Off — Requires the modem reset $\overline{\text{RST}}$ input to stay asserted low. Lowest possible power and all functions are disabled. Digital GPIO default to inputs
- Hibernate — Has next lowest power, all hardware blocks deactivated, RAM and SPI register data are retained. Digital I/O retain their state
- Doze — Allows use of the Event Timer when active. The Event Timer can be used to cause a timed exit from Doze, and the CLKO output can be kept active in Doze to provide a clock to the MCU.

Doze uses considerable more current than Off or Hibernate. RAM and register data are retained and digital I/O retain their state

Table 3-5. MC13201 Modem Low Power States

Mode	Current (typ @ 2.7V)	Advantages	Disadvantages	Comment
Off	1 µA	Lowest power (leakage only)	Digital outputs tristated. All RAM/register data lost.	$\overline{\text{RST}}$ must remain asserted. All IC functions off.
Hibernate	2.3 µA	RAM/register data retained. Digital outputs retain their states.		$\overline{\text{ATTN}}$ or $\overline{\text{M\_RST}}$ used to exit state.
Doze[1]	35 µA (no CLKO)	Crystal reference oscillator is on and CLKO can be enabled. Timed exit is possible. RAM/register data retained. Digital outputs retain their states.	Much higher current than Hibernate or Off.	Can exit on $\overline{\text{ATTN}}$ or $\overline{\text{RST}}$ or timed exit is option. CLKO can be kept active as a clock source.
Idle	500 µA	Fast transition to RX, TX, CCA	Much higher current than Doze or Hibernate	State from which all TX, RX or CCA is initiated.

[1] CLKO frequency at default value of 37.786 kHz.

Although Idle is not considered a low power state, it is listed in Table 3-5 for comparison. It is also important to remember that all active states of RX, TX and CCA must be initiated from the Idle condition.

3.10.2 Special Consideration Where Doze Current Is Higher Than Specified

The Doze current (no CLKO output active) is specified as 35 µA (typical) on the data sheet with the programmed CLKO frequency at a default of 32.786 kHz. The Doze current can be considerably higher for certain combinations of higher CLKO frequencies and event timer prescale options. These combinations consist of:

1. CLKO frequency = 16 MHz with prescale select at 5, 6, or 7.
2. CLKO frequency = 8 MHz with prescale select at 6, or 7.
3. CLKO frequency = 4 MHz with prescale select at 7.

All other combinations have no problems. The higher current will not occur every time Doze is enabled. There is no potential harm either to the transceiver or its operation, the Doze current is simply higher.

To work around this issue, there are three choices:

1. Accept higher current in Doze mode.
2. Do not use any of the described combinations in Doze mode.
3. If a higher CLKO frequency is desired when using CLKO as an MCU clock source, and the desired prescale select can cause a problem, just before entering Doze mode, program the CLKO frequency to a lower value. Next, use the desired prescale value while in Doze. Finally, after exiting Doze mode, reprogram CLKO to the desired frequency before releasing the MCU clock to the CLKO source.

3.10.3 Low Power Exit Using $\overline{\text{ATTN}}$

Although a hardware reset will also cause the MC13201 to exit a low power state, the standard means to exit is use of $\overline{\text{ATTN}}$. The $\overline{\text{ATTN}}$ input is asserted by a high-to-low signal transition.

- If the transceiver is active (not in Hibernate or Doze), a high-to-low $\overline{\text{ATTN}}$ signal transition is ignored and has no effect.
- $\overline{\text{ATTN}}$ can be negated (low-to-high transition) at any time and has no effect.
- When the transceiver is fully in Hibernate or Doze, $\overline{\text{ATTN}}$ may be asserted at any time.
- When the transceiver is entering Hibernate or Doze, $\overline{\text{ATTN}}$ may be asserted at any time EXCEPT during the final cycle of CLKO (see Figure 3-7) -
  - — Background - A SPI command is written to the transceiver to initiate a low power mode. The transceiver continues to run CLKO for 128 clock cycles after the command is recognized; this is true whether or not the external CLKO output is enabled. After completion of the last clock cycle, the transceiver completes the transition to low power
  - — $\overline{\text{ATTN}}$ can be asserted any time except for the last CLKO clock cycle. If $\overline{\text{ATTN}}$ does assert during this period, the transition is ignored and the transceiver continues into low power mode. The expected wake-up will not occur.

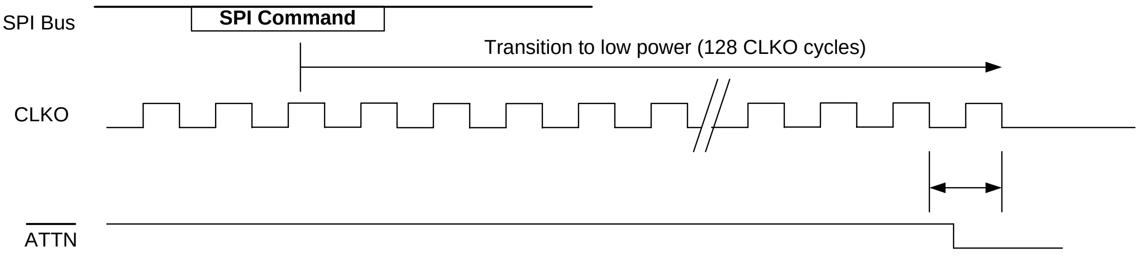


Figure 3-7. Disallowed Timing for $\overline{\text{ATTN}}$ Transition

  - — Preventative strategies -
    - – Do not assert $\overline{\text{ATTN}}$ during the power down sequence - be sure a sufficient delay is provided as to prevent $\overline{\text{ATTN}}$ going active until the transceiver is fully in low power mode.
    - – Cycle $\overline{\text{ATTN}}$ twice - if it is difficult to be sure $\overline{\text{ATTN}}$ does not cycle too soon, $\overline{\text{ATTN}}$ can be asserted more than once to be sure to cause the wake-up. The cycle time between the high-to-low edges should be longer than the cycle time of CLKO during power down.
    - – Speed-up CLKO frequency before power down to shorten power down delay - CLKO can be used at its default 32.786 kHz frequency and the elapsed time for 128 CLKO cycles is ~3.9 ms. This time can be reduced to ~8 µs if CLKO is reprogrammed to 16 MHz just before entering low power mode. This can help in applications where a quick turnaround from low power to normal operation is desired at certain times.

3.10.4 Recovery Times from Low Power Modes

The mode of operation is controlled by the MCU. The modem may be powered down if it is not in use while the MCU is doing another task or while the whole node is “sleeping”, i.e., the MCU is also powered down. Recovery time for both the modem and the MCU are important to system performance and the recovery times are independent of each other.

Each of the modem recovery times is from the low power condition to the Idle state. The start-up times for the Off and Hibernate conditions are considerably longer due to the start-up of the voltage regulators and clock oscillator. Figure 3-8 shows a simplified state diagram for the low power modes and gives the transition time to Idle:

- Off > Idle (10 - 25 ms) — The Off state is released by negating $\overline{\text{RST}}$ high. From that time until the modem asserts a $\overline{\text{ATTN}}$ interrupt and CLKO starts with a default frequency of 32.786+ kHz is 25 ms maximum.
- Hibernate > Idle (8 - 20 ms) — The Hibernate state is normally released via asserting $\overline{\text{ATTN}}$ low. The start-up time at 20 ms maximum is a little quicker than from the Off condition. The modem also asserts a ATTN interrupt (if enabled) and CLKO starts (if enabled) with the value programmed before entering Hibernate.
- Doze > Idle ((300 + 1/CLKO) µs) — The Doze state can be released via a timer or asserting $\overline{\text{ATTN}}$ low. The start-up time is considerably less ((300 + 1/CLKO) µs) because the clock oscillator is already running. CLKO can be programmed to run during Doze, and if not, CLKO will start in enabled for normal operation. An $\overline{\text{ATTN}}$ interrupt will be asserted (if enabled) when $\overline{\text{ATTN}}$ is used to exit Doze, or an interrupt will be asserted for exiting Doze Mode via a timer.

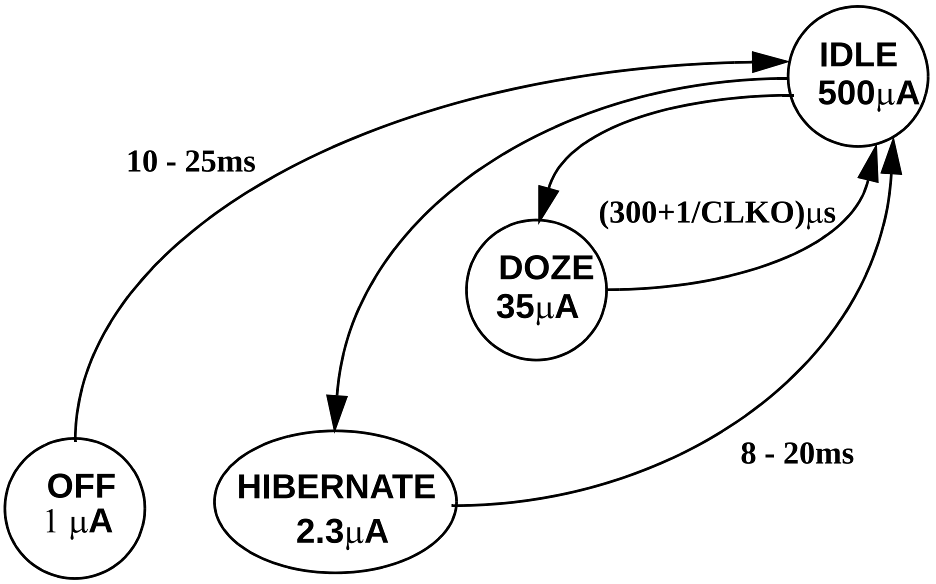


Figure 3-8. MC13201 Modem Low Power Recovery Times

3.10.4.1 Modem Active Currents

In normal operational mode the modem's rest state in the Idle Mode. All active sequences originate from the Idle Mode and return to the Idle Mode. The three active sequences are Clear Channel Assessment (CCA), RX, and TX, and each has a separate current profile. Table 3-6 lists the typical currents while in the listed modes, but does not show the transition profiles when moving between modes.

Table 3-6. MC13201 Active State Currents

Mode	Current (typ @ 2.7V)
Idle	500 µA
CCA/ED	37 mA
RX	37 mA
TX (0 dBm nominal output power)	30 mA

A normal sequence of events may include a 802.15.4 Standard node performing first a CCA to see if the channel is clear, second transmitting a frame (assuming the channel is clear), and finally after the TX, going into to Receive Mode to look for an acknowledge. The modem must be programmed for each of the operations separately and each operation has a different timing profile.

3.10.4.1.1 Modem CCA/ED Timing profile

The modem will scan for detected energy in a CCA operation (CCA is covered in detail in Section 6.3.4, “Clear Channel Assessment (CCA) Modes (including Link Quality Indication)). This is really a special case of RX so the CCA current is the same as RX. There are two versions of CCA where one is called CCA and the second is called Energy Detect (ED).

Figure 3-9 shows the timing profiles for both variations of a CCA operation. Once the CCA operation is initiated, the state machine moves through a warm-up period of 144 µs in which the analog regulators turn on and the analog RX circuitry comes to full power. The actual CCA or ED operation lasts 134 µs or 198 µs, respectively. During the warm-up period, the modem current is ramping from idle current (typically 500 µA) to full CCA current (typically 37 mA). The modem current for the CCA or ED is the full CCA current. After the CCA/ED operation times out, the return to idle current is very quick.

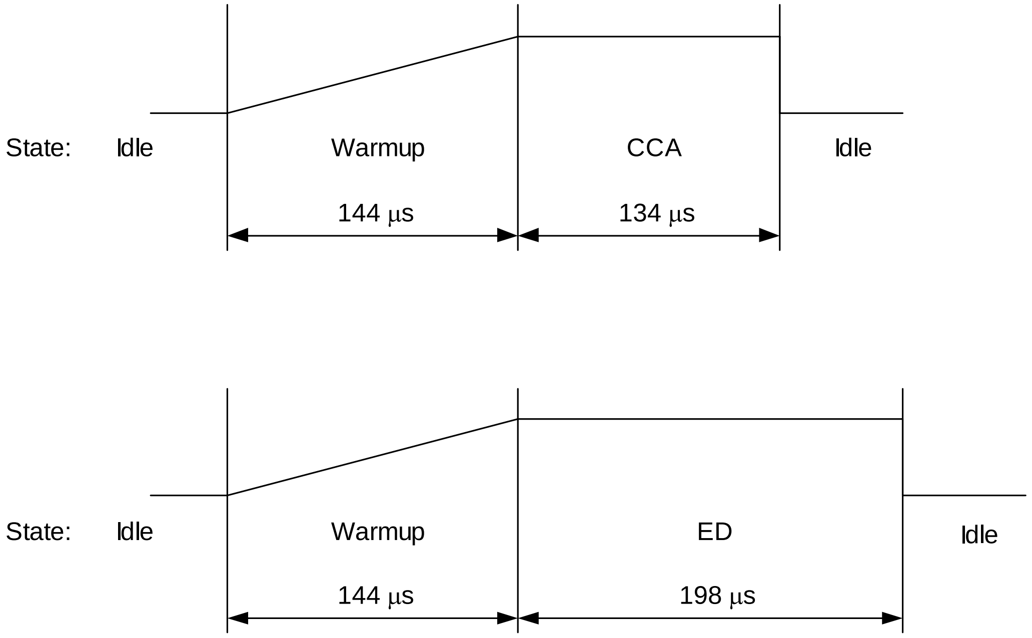


Figure 3-9. CCA and ED Timing Profiles

3.10.4.1.2 Modem RX Timing profile

The receive or RX timing profile is very similar to the CCA profile. Figure 3-10 shows the timing profile for an RX operation. There is the initial 144 µs warm-up period from idle current to full RX current (typically 37 mA) followed by the RX operation (RX is covered in detail in Section 6.3, “Active Modes). The RX time is not a set figure as it is in a CCA operation. In some applications (typically not battery operated) such as a Coordinator, the receiver can be turned on for a majority of the timer listening for End Devices or Routers. In an End Device (typically battery operated), the receiver can be typically turned on only when expecting an acknowledgement (ACK) of a transmission. The worst case RX on time can be when no ACK is received and the RX operation times out with not having received a frame.

The RX operation will end based on receiving the end of a frame or being terminated by the application having timed-out and aborted the RX operation. The return to Idle happens very quickly.

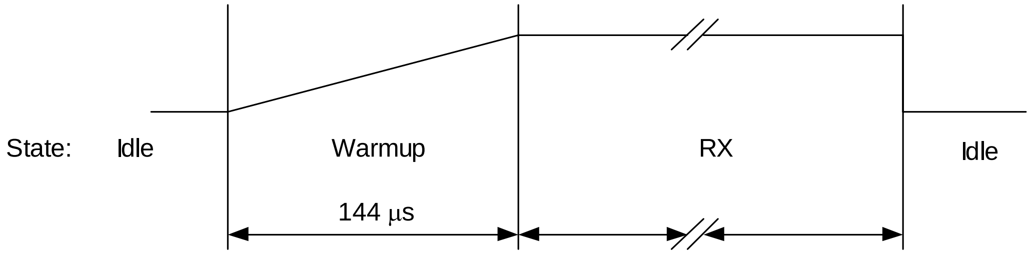


Figure 3-10. RX Timing Profile

3.10.4.1.3 Modem TX Timing profile

The transmit or TX timing profile is more predictable than the RX profile. Figure 3-11 shows the timing profile for a TX operation. There is the usual initial 144 µs warm-up period from idle current to full TX current (typically 30 mA) followed by the TX operation (TX is covered in detail in Section 6.3, “Active Modes). The TX time is not a set figure but it is predictable.

The raw transmission rate of the 802.15.4 Standard 2.4 GHz physical layer is 62.5 ksymbols/s or 250 kb/s. This means the TX time for 2 symbols or 1 byte of data is 32 µs. An 802.15.4 2.4 Standard compliant packet has 4 bytes of preamble, 1 byte of SFD, 1 byte of FLI, 2 bytes of FCS plus the payload data (125 bytes maximum). As a result the, the overhead of a frame is 8 bytes or 8 x 32 = 256 µs, and the maximum payload TX time is 125 x 32 = 4000 µs. The TX time for a packet then is:

Total TX time (µs) = 256 + (payload bytes x 32)

The TX operation will end after the FCS bytes are sent. The return to Idle has a “warm down” period of 10 µs to allow the RF transmitter to taper off in a manner to avoid RF “splatter”.

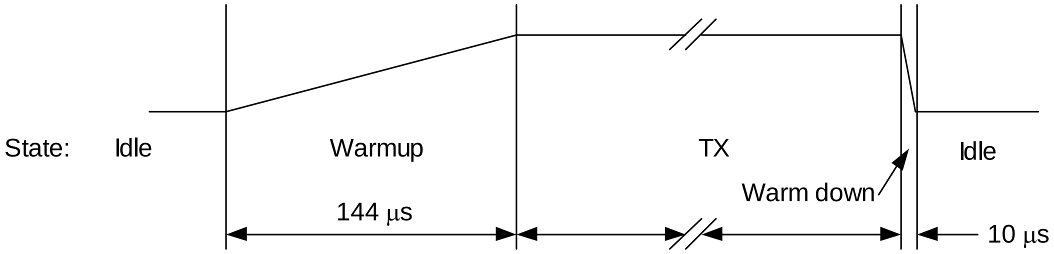


Figure 3-11. TX Timing Profile

3.10.5 General System Considerations for Low Power

Low power is most important for battery operated applications such as 802.15.4 Standard End Devices. In the modem the highest instantaneous power is dominated by the CCA, RX and TX modes. In the MCU, the current draw is typically dominated by the clock frequency. A number of general recommendations can help the user:

- Clock Management on the MCU
  - Use clock management as required to lower required power
  - Run fast when the CPU performance is the critical path
  - Run slow when waiting on peripherals (such as ATD conversion)
  - Be aware of software performance requirements (run time bus clock may need to be 16 MHz)
  - Use the external clock option for lowest power if possible (modem CLKO can supply frequencies as high as 16 MHz)
- The MCU can go to a lower power mode when the modem is recovering from the Off (10 - 25 ms) or the Hibernate modes
- When the MCU is initializing from a “cold start” POR condition, the modem reset must be driven to a low condition early in the routine. This is so the modem will start from a known condition and low power

- Profile the use scenario of both the modem and the MCU when they are active. This is required to estimate current usage versus time and mode of operation
- If possible put the modem in a low power mode, when the MCU is active and does not require interface with the modem. Doze can be useful to save power, provide CLKO, and be ready with a quick recovery time
- Alternately put the MCU in a lower power mode if waiting on the modem IRQ
- Program all unused GPIO on both the modem and the MCU as outputs for lowest power
- The default condition is for MISO to go to tristate when $\overline{\text{CE}}$ is de-asserted. Program Control_B Register 07, Bit 11, miso_hiz_en = 0 so MISO will be driven low when $\overline{\text{CE}}$ is de-asserted. As a result MISO will not float when Doze or Hibernate mode is enabled

Chapter 4
Modem SPI Register Descriptions

4.1 Overview

All control, reading of status, writing of data, and reading of data is done through the MC13201 SPI port. The host microcontroller accesses the transceiver through SPI "transactions" in which multiple bursts of byte-long data are transmitted on the SPI bus. Each transaction is three or more bursts long depending on the transaction type, and these are described in detail in Section 5.3, "SPI Singular Transactions.

Transactions are always read accesses or write accesses to register addresses. The associated data for any single register access is always 16 bits in length. This chapter describes all the registers that users should access in the MC13201. Undocumented addresses should not be accessed.

NOTE

- Register default values for reserved fields should not be modified unless specifically noted. Freescale recommends that all writes to control register fields that only modify part of the 16-bit word be done as a read-modify-write operation.
- The newest version of the MC13201 now uses an updated transceiver device. Although fully compliant with earlier versions of the transceiver, proper performance of the radio requires that the following modem registers be over-programmed:

  Register 0x31 to 0xA0C0

  Register 0x34 to 0xFEC6

These registers must be over-programmed for MC13201 devices in which the modem Chip_ID Register 0x2C reads 0x6800. These register updates must be added to software that has been running on previous versions of the MC13201.

4.2 Register Model and Description Details

Table 4-1 summarizes the MC13201 Register Model and the following sections describe each register in more detail.

Table 4-1. Modem SPI Register Table

REGISTER NAME	Add (Hex)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reset	00	software_reset															
RX_Pkt_RAM	01	rx_pkt_ram[15:0]															
TX_Pkt_RAM	02	tx_pkt_ram[15:0]															
TX_Pkt_Ctl	03										tx_pkt_length[6:0]						
CCA_Thresh	04	cca_vt[7:0]								power_comp[7:0]							
IRQ_Mask	05	attn_mask			ram_addr_mask	arb_busy_mask		pll_lock_mask	acoma_en				doze_mask			tmr2_mask	tmr1_mask
Control_A	06						cca_mask	tx_sent_mask	rx_rcvd_mask	tmr_trig_en		cca_type[1:0]				xcvr_seq	
Control_B	07	tmr_load	ct_bias_en	ct_bias_inv	RF_switch_mode	miso_hiz_en		clko_doze_en								hib_en	doze_en
PA_Enable	08	pa_en															
Control_C	09									gpio_alt_en		clko_en			tmr_prescale[2:0]		
CLKO_Ctl	0A	xtal_trim[7:0]													clko_rate[2:0]		
GPIO_Dir	0B	gpio1234_drv[1:0]		gpio7_oen	gpio6_oen	gpio5_oen	gpio4_oen	gpio3_oen	gpio2_oen	gpio1_oen	gpio7_ien	gpio6_ien	gpio5_ien	gpio4_ien	gpio3_ien	gpio2_ien	gpio1_ien

Table 4-1. Modem SPI Register Table (continued)

REGISTER NAME	Add (Hex)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GPIO_Data_Out	0C	gpio567_drv[1:0]		miso_drv[1:0]		clko_drv[1:0]		irqb_drv[1:0]		irqb_pup_en	gpio7_o	gpio6_o	gpio5_o	gpio4_o	gpio3_o	gpio2_o	gpio1_o
LO1_Int_Div	0F									lo1_idiv[7:0]							
LO1_Num	10	lo1_num[15:0]															
PA_Lvl	12									pa_lvl_coarse[1:0]		pa_lvl_fine[1:0]		pa_drv_coarse[1:0]		pa_drv_fine[1:0]	
Tmr_Cmp1_A	1B	tmr_cmp1_dis								tmr_cmp1[23:16]							
Tmr_Cmp1_B	1C	tmr_cmp1[15:0]															
Tmr_Cmp2_A	1D	tmr_cmp2_dis								tmr_cmp2[23:16]							
Tmr_Cmp2_B	1E	tmr_cmp2[15:0]															
IRQ_Status	24	pll_lock_irq	ram_addr_err	arb_busy_err			attn_irq	doze_irq	tmr1_irq	rx_rcvd_irq	tx_sent_irq	cca_irq			tmr2_irq	cca	crc_valid
RST_Ind	25									reset_ind							
Current_Time_A	26									et[23:16]							
Current_Time_B	27	et[15:0]															
GPIO_Data_In	28		gpio7_i	gpio6_i	gpio5_i	gpio4_i	gpio3_i	gpio2_i	gpio1_i								
Chip_Id	2C	chip_id[8:0]															
RX_Status	2D	cca_final[7:0]									rx_pkt_latch[6:0]						
Timestamp_A	2E									timestamp[23:16]							
Timestamp_B	2F	timestamp[15:0]															

Table 4-1. Modem SPI Register Table (continued)

REGISTER NAME	Add (Hex)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BER_Enable	30	ber_en															
PSM_Mode	31											psm_tm[2:0]					
Reserved	34																

4.3 Reset - Register 00

Writing to Reset Register 00 causes a reset condition where the digital logic is reset, but the transceiver is not powered down. The device is forced to the Idle Mode and the SPI registers are all reset and forced to their default condition although all data in the Packet RAMs is retained. The reset is held as long as $\overline{CE}$ remains asserted and is released when $\overline{CE}$ is negated high. A read of this register has no effect.

Register 00 0x00

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	software_reset															
TYPE	w															
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0x0000															

Table 4-2. Register 00 Description

Name	Description	Operation
Bits 15-0	**software_reset** — Writing this register provides a software reset. When there is a SPI write to Register 00, the IC is reset and stays reset as long as CE remains asserted, and returns to normal operation when CE is negated. Read of this register has no effect.	Write data is “don’t care”

4.4 RX_Pkt_RAM - Register 01

The receive Packet RAM register is accessed when the MC13201 is being used for RX data transfer. Once a packet has been received, the payload data is stored in the RX Packet RAM and the length of the packet data is contained in Register 2D, Bit 6-0. A recursive read (see Section 5.5, “SPI Recursive Transactions) to the RX_Pkt_RAM Register 01 is required to access the RX packet payload data.

Register 01 0x01

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	rx_pkt_ram[15:0]															
TYPE	r/w															
RESET	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	unknown from reset															

Table 4-3. Register 01 Description

Name	Description	Operation
Bits 15-0	**rx_pkt_ram[15:0]** — These bits are the data channel for host access to the receive Packet RAM.	Default from $\overline{\text{RST}}$ reset is indeterminate.

4.5 TX_Pkt_RAM - Register 02

The transmit Packet RAM register is accessed for TX data transfer. The packet payload data must be written to the TX Packet RAM and the length of the packet data must be written to TX_Pkt_Ctl Register 03, Bits 6-0. A recursive write (see Section 5.5, “SPI Recursive Transactions) to the TX_Pkt_RAM Register 02 is required to load the TX packet payload data.

Register 02 0x02

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tx_pkt_ram[15:0]															
TYPE	r/w															
RESET	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	unknown from reset															

Table 4-4. Register 02 Description

Name	Description	Operation
Bits 15-0	**tx_pkt_ram[15:0]** — These bits are the data channel for host access to the selected transmit Packet RAM.	Default from reset is indeterminate.

4.6 TX_Pkt_Ctl - Register 03

The TX_Pkt_RAM_Ctl Register 03 contains a field tx_pkt_length, Bits 6-0, that defines the length of the payload data for a transmission data packet.

Register 03 0x03

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
										tx_pkt_length[6:0]						
TYPE										r/w						
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0x0000															

Table 4-5. Register 03 Description

Name	Description	Operation
Bits 15- 7	Reserved	Leave default
Bits 6 - 0	**tx_pkt_length[6:0]** — The Transmit Packet Length bits represent the number of bytes to be transmitted from transmit Packet RAM plus 2 bytes for FCS.	Total transmit payload data length in bytes

4.7 CCA_Thresh - Register 04

The CCA_Thresh Register 04 contains the cca_vt[7:0] 8-bit CCA threshold value, Bits 15 - 8. To calculate desired the cca_vt[7:0] value:

Threshold value = hex (| (Threshold Power in dBm) * 2 |)

A second field is power_comp[7:0], Bits 7 - 0, which is an offset that is divided by 2 and added to the measured value of the average energy from a CCA/ED function or LQI value from an RX function, and the resulting value is stored in cca_final[7:0], RX_Status Register 2D. By using this power_comp[7:0] value, users can compensate the cca_final[7:0] value for external gain in the RX path. See Section 6.3.4, "Clear Channel Assessment (CCA) Modes (including Link Quality Indication) for more detailed information.

NOTE

The default value for power_comp[7:0] is 0x8D. To center the reported cca_final[7:0] value over temperature, it is suggested that a value of 0x9B be written to power_comp[7:0], which equates to a 3.5dBm offset from default.

Register 04 0x04

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	cca_vt[7:0]								power_comp[7:0]							
TYPE				r/w												
RESET	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1

0x008D

Table 4-6. Register 04 Description

Name	Description	Operation
Bits 15-8	**cca_vt[7:0]** - Threshold value for Clear Channel Assessment in dB-linear format	Default is 0x00.
Bits 7-0	**power_comp[7:0]** - This is a binary value that is added to the measured value of the CCA operation. The result is stored in cca_final[7:0]	Default is 0x8D

4.8 IRQ_Mask - Register 05

The IRQ_Mask Register 05 provides most, but not all, mask bits for various interrupt sources for the MC13201. If a mask bit is set, its associated status bit being true will generate an interrupt on the MC13201 IRQ pin. The interrupt is cleared when the status bit is read via a SPI transaction.

Register 05 0x05

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	attn_mask			ram_addr_mask	arb_busy_mask		pll_lock_mask	acoma_en				doze_mask			tmr2_mask	tmr1_mask
TYPE	r/w			r/w		r/w	r/w	r/w				r/w	r/w	r/w	r/w	r/w
RESET	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

0x8040

Table 4-7. Register 05 Description

Name	Description	Operation
Bits 14-13, 10, 7-5,3-2	Reserved	Leave default
Bit 15	**attn_mask** — The attention interrupt mask bit controls the attn_irq interrupt on the IRQ pin. Default is for the interrupt to be enabled out of reset.	1 = Allows attn_irq to generate an interrupt on the IRQ pin. 0 = When attn_irq status bit is set, IRQ pin is not asserted.

Table 4-7. Register 05 Description (continued)

Name	Description	Operation
Bit 12	**ram_addr_mask** — The Packet RAM address error interrupt mask bit controls the ram_addr_err interrupt on the IRQ pin.	1 = Allows ram_addr_err to generate an interrupt on the IRQ. 0 = When ram_addr_err status bit is set, IRQ pin is not asserted.
Bit 11	**arb_busy_mask** — The Packet RAM arbiter busy error interrupt mask bit controls the arb_busy_err interrupt on the IRQ pin.	1 = Allows arb_busy_err to generate an interrupt on the IRQ pin. 0 = When arb_busy_err status bit is set, IRQ pin is not asserted.
Bit 9	**pll_lock_mask** — The LO1 unlock detect mask bit controls the pll_lock_irq interrupt on the IRQ pin.	1 = Allows pll_lock_irq to generate an interrupt on the IRQ pin. 0 = When pll_lock_irq status bit is set, IRQ pin is not asserted.
Bit 8	**acoma_en** — The Acoma Mode enable bit controls Doze Mode. Acoma is an enhanced power save mode within Doze.	1 = The MC13201 stays in Doze until $\overline{\text{ATTN}}$ asserted. Event Timer and Prescaler clocks disabled for additional current savings. 0 = Normal operation. Doze is exited by TC2 match or $\overline{\text{ATTN}}$ assertion.
Bit 4	**doze_mask** — The Doze timer interrupt mask bit controls the doze_irq interrupt on the IRQ pin.	1 = Allows doze_irq to generate an interrupt on the IRQ pin. 0 = When doze_irq status bit is set, IRQ pin is not asserted.
Bit 1	**tmr2_mask** — The Event Timer two interrupt mask bit controls the tmr2_irq interrupt on the IRQ pin.	1 = Allows tmr2_irq to generate an interrupt on the IRQ pin. 0 = When tmr2_irq status bit is set, IRQ pin is not asserted.
Bit 0	**tmr1_mask** — The Event Timer one interrupt mask bit controls the tmr1_irq interrupt on the IRQ pin.	1 = Allows tmr1_irq to generate an interrupt on the IRQ pin. 0 = When tmr1_irq status bit is set, IRQ pin is not asserted.

4.9 Control_A - Register 06

The Control_A Register 06 is one of several registers that provide control fields for the MC13201.

Register 06 0x06

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						cca_mask	tx_sent_mask	rx_rcvd_mask	tmr_trig_en		cca_type[1:0]				xcvr_seq	
TYPE						r/w	r/w	r/w	r/w		r/w				r/w	
RESET	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0

0x4010

Table 4-8. Register 06 Description

Name	Description	Operation
Bits 15-11, 6,3,2	**Reserved**	Leave default
Bit 10	**cca_mask** — The CCA interrupt mask bit controls the cca_irq interrupt on the IRQ pin.	1 = Allows the cca_irq to generate an interrupt on the IRQ pin. 0 = When icca_irq status bit is set, IRQ pin is not asserted.
Bit 9	**tx_sent_mask** — The transmit sent mask bit controls the tx_sent_irq interrupt on the IRQ pin.	1 = Allows the tx_sent_irq to generate an interrupt on the IRQ pin. 0 = When tx_sent_irq status bit is set, IRQ pin is not asserted.
Bit 8	**rx_rcvd_mask** — The packet received interrupt mask bit controls the rx_rcvd_irq interrupt on the IRQ pin.	1 = Allows rx_rcvd_irq to generate an interrupt on the IRQ pin. 0 = When rx_rcvd_irq status bit is set, IRQ pin is not asserted.
Bit 7	**tmr_trig_en** — The timer trigger enable bit determines whether transceiver operation is initiated via Timer Comparator 2 or manually.	1 = The selected transceiver operation is initiated via Timer Comparator 2, or TC2_Prime. 0 = The selected transceiver operation is initiated manually via the RXTXEN pin and by SPI programming.
Bits 5-4	**cca_type[1:0]** — The clear channel assessment type bits selects one of two possible CCA functions. Algorithm results are reported in field cca_final[7:0], RX_Status Register 2D, Bits 15 - 8.	01 = clear channel assessment 10 = energy detection
Bits 1-0	**xcvr_seq[1:0]** — The transceiver operation bits select one of four possible transceiver modes.	00 = Idle (default) 01 = CCA /energy detection 10 = Packet Mode RX 11 = Packet Mode TX

4.10 Control_B - Register 07

The Control_B Register 07 is one of several registers that provide control fields for the MC13201.

Register 07 0x07

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tmr_load	ct_bias_en	ct_bias_inv	RF_switch_mode	miso_hiz_en		clko_doze_en								hib_en	doze_en
TYPE	r/w	r/w	r/w	r/w	r/w		r/w		r/w	r/w	r/w				r/w	r/w
RESET	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0

0x0C00

Table 4-9. Register 07 Description

Name	Description	Operation
Bits 10, 8-2	Reserved	Leave default
Bit 15	**tmr_load** — The load Event Timer bit, when programmed from low to high, causes the value of the SPI field tmr_cmp1[23:0] to be loaded into the Event Timer.	Write from 0 to 1 to affect load. Rewrite to 0, before writing another 1 to affect another load.
Bit 14	**ct_bias_en** — The CT_Bias enable bit controls when the signal CT_Bias is active.	1 = CT_Bias enabled. Output state is defined by Table 4-9. 0 = CT_Bias disabled. Output state is tristated.
Bit 13	**ct_bias_inv** — The CT_Bias Invert bit inverts the sense of the CT_Bias output signal when the CT_Bias is used as a control signal for dual port operation	The output state of CT_Bias under varying conditions is defined in Table 4-9. 1 = CT_Bias inverted. 0 = CT_Bias not inverted
Bit 12	**RF_switch_mode** — This bit selects the mode of operation of the RF interface, i.e., between Dual Port Mode and Single Port Mode.	1= Single Port Mode selected where RF switch is active and RFIN_M and RFIN_P and bidirectional signals. 0 = Dual Port Mode selected where RFIN_M and RFIN_P are inputs only and PAO_P and PAO_N are separate outputs. (This is default operation).
Bit 11	**miso_hiz_en** — The MISO high impedance enable bit either tristates or drives the MISO pin to a logic low when $\overline{CE}$ is negated.	1 = MISO pin is tristated when $\overline{CE}$ is negated. 0 = MISO pin is driven to a logic low when $\overline{CE}$ is negated. It is recommended to program **miso_hiz_en** = 0 for low power modes.
Bit 9	**clko_doze_en** — The CLKO enable in Doze Mode bit controls toggling of the CLKO pin during Doze Mode.	1 = The CLKO pin continues to toggle at selected rate during Doze Mode if CLKO is enabled (clko_en = 1). 0 = The CLKO pin stops toggling 128 xtal or reference cycles after the **doze_en bit** is programmed to 1. **Note:** In Doze Mode only, CLKO frequencies of 1.0 MHz or less are available.

Table 4-9. Register 07 Description (continued)

Name	Description	Operation
Bit 1	**hib_en** — The hibernate enable bit can set the MC13201 into its lowest power saving mode without a running time base.	1 = Places the MC13201 into its lowest power operating mode without a running time base. 0 = Normal operation.
Bit 0	**doze_en** — The doze enable bit can set the MC13201 into its lowest power saving mode with a running time base.	1 = Places the MC13201 into its lowest power operating mode with a running time base. 0 = Normal operation.

4.11 PA_Enable - Register 08

The PA_Enable Register 08 contains the power amp (PA) enable bit which turns on and off the transmitter outputs. This feature is useful for sequences in RF test configurations. The default condition is with the transmitter enabled.

Register 08 0x08

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	pa_en															
TYPE	r/w															
RESET	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1

0xFFF7

Table 4-10. Register 08 Description

Name	Description	Operation
Bits 14-0	Reserved	
Bit 15	**pa_en** — The power amp (PA) enable bit controls the transmitter PA outputs.	1 = PA enabled. 0 = PA disabled; the transmitter puts out no power.

4.12 Control_C - Register 09

The Control_C Register 09 is one of several registers that provide control fields for the MC13201.

Register 09 0x09

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									gpio_alt_en		clko_en			tmr_prescale[2:0]		
TYPE									r/w		r/w			r/w		
RESET	1	1	1	1	0	0	1	1	0	1	1	0	1	0	1	1

0xF36B

Table 4-11. Register 09 Description

Name	Description	Operation
Bits 15-8, 6, 4, 3	Reserved	Leave default
Bit 7	**gpio_alt_en** — The GPIO alternative MCU interface enable bit controls GPIO1 and GPIO2.	1 = GPIO1 and GPIO2 are used as status to the MCU. GPIO1 indicates when the MC13201 is out of idle. GPIO2 indicates a valid CRC or CCA result. These signals are required for Freescale's 802.15.4 MAC software. 0 = Normal GPIO operation.
Bit 5	**clko_en** — This bit enables the clock output which can be used as a reference clock for the MCU. Frequency is dependent on the value of clko_rate[2:0] (Register 0A, Bits 2 - 0).	1 = Output enabled (default). 0 = Output low
Bits 2-0	**tmr_prescale[2:0]** — The Event Timer prescale value bits select the frequency of the base clock for the Event Timer module.	See Chapter 7, "Timer Information for more information.

4.13 CLKO_Ctl - Register 0A

The MC13201 provides the ability to trim the crystal oscillator frequency and an output clock with a programmable frequency that can be used to drive another device, such as a microcontroller. The field xtal_trim[7:0], CLKO_Ctl Register 0A, Bits 15-8, alter the capacitive loading to the crystal and affects the oscillator frequency. See Chapter 9, "Miscellaneous Functions.

The CLKO frequency is programmed using clko_rate[2:0], CLKO_Ctl Register 0A, Bits 2-0. Table 4-12 lists each setting and its respective frequency.

Table 4-12. CLKO Frequency

clko_rate	CLKO
000	16 MHz
001	8 MHz
010	4 MHz
011	2 MHz
100	1 MHz
101	62.5 kHz
110 (default)	32.786+ kHz = 16 MHz / 488
111	16.393+ kHz = 16 MHz / 976

Register 0A 0x0A

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	xtal_trim[7:0]								▨	▨	▨	▨	▨	clko_rate[2:0]		
TYPE	r/w													r/w		
RESET	0	1	1	1	1	1	1	0	1	0	0	0	0	1	1	0
	0x7E86															

Table 4-13. Register 0A Description

Name	Description	Operation
Bits 7-3	Reserved	Leave default
Bits 15-8	**xtal_trim[7:0]** — The crystal oscillator capacitor trim bits warps the crystal frequency by approximately -0.25 ppm per bit.	0x7E is the default setting and suggested start point for trimming.
Bits 2-0	**clko_rate[2:0]** — The CLKO rate bits select the clock frequency of the CLKO pin.	See Table 4-12.

4.14 GPIO_Dir - Register 0B

The GPIO_Dir Register 0B contains control bits for GPIO1 through GPIO7 that configure the data direction of each GPIO as well as a control field that sets the output drive strength of GPIO1 through GPIO4. Each GPIO bit has a corresponding bit to set the GPIO as an output and a separate corresponding bit to set the GPIO as an input. If both enable bits are set simultaneously for a given GPIO, the GPIO is configured as an input (input setting wins). During a hardware reset on $\overline{\text{RST}}$, all the GPIO are tristated and the GPIO default to inputs.

Register 0B 0x0B

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	gpio1234_drv[1:0]		gpio7_oen	gpio6_oen	gpio5_oen	gpio4_oen	gpio3_oen	gpio2_oen	gpio1_oen	gpio7_ien	gpio6_ien	gpio5_ien	gpio4_ien	gpio3_ien	gpio2_ien	gpio1_ien
TYPE	r/w		r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w
RESET	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1

0x007F

Table 4-14. Register 0B Description

Name	Description	Operation
Bits 15-14	**gpio1234_drv[1:0]**— These bits select output drive strength for GPIO1 through GPIO4.	00 (default) = lowest drive strength; 11 = highest drive strength.
Bit 13	**gpio7_oen**— This bit configures GPIO7 as an output.	1 = GPIO7 enabled as output. 0 = GPIO7 disabled as output.
Bit 12	**gpio6_oen**— This bit configures GPIO6 as an output.	1 = GPIO6 enabled as output. 0 = GPIO6 disabled as output.
Bit 11	**gpio5_oen**— This bit configures GPIO5 as an output.	1 = GPIO5 enabled as output. 0 = GPIO5 disabled as output.
Bit 10	**gpio4_oen**— This bit configures GPIO4 as an output.	1 = GPIO4 enabled as output. 0 = GPIO4 disabled as output.
Bit 9	**gpio3_oen**— This bit configures GPIO3 as an output.	1 = GPIO3 enabled as output. 0 = GPIO3 disabled as output.
Bit 8	**gpio2_oen**— This bit configures GPIO2 as an output.	1 = GPIO2 enabled as output. 0 = GPIO2 disabled as output.
Bit 7	**gpio1_oen**— This bit configures GPIO1 as an output.	1 = GPIO1 enabled as output. 0 = GPIO1 disabled as output.
Bit 6	**gpio7_ien**— This bit configures GPIO7 as an input.	1 = GPIO7 enabled as input. 0 = GPIO7 disabled as input.
Bit 5	**gpio6_ien**— This bit configures GPIO6 as an input.	1 = GPIO6 enabled as input. 0 = GPIO6 disabled as input.

Table 4-14. Register 0B Description (continued)

Name	Description	Operation
Bit 4	**gpio5_ien**— This bit configures GPIO5 as an input.	1 = GPIO5 enabled as input. 0 = GPIO5 disabled as input.
Bit 3	**gpio4_ien**— This bit configures GPIO4 as an input.	1 = GPIO4 enabled as input. 0 = GPIO4 disabled as input.
Bit 2	**gpio3_ien**— This bit configures GPIO3 as an input.	1 = GPIO3 enabled as input. 0 = GPIO3 disabled as input.
Bit 1	**gpio2_ien**— This bit configures GPIO2 as an input.	1 = GPIO2 enabled as input. 0 = GPIO2 disabled as input.
Bit 0	**gpio1_ien**— This bit configures GPIO1 as an input.	1 = GPIO1 enabled as input. 0 = GPIO1 disabled as input.

4.15 GPIO_Data_Out - Register 0C

The GPIO_Data_Out Register 0C contains a bit for each GPIO that sets its output value if the GPIO is configured as an output as well as a control fields that set the output drive strength of GPIO5 through GPIO7, MISO, CLKO, and $\overline{\text{IRQ}}$. This register also contains the pullup enable for the $\overline{\text{IRQ}}$ pin.

Register 0C 0x0C

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	gpio567_drv[1:0]		miso_drv[1:0]		clko_drv[1:0]		irqb_drv[1:0]		irqb_pup_en	gpio7_o	gpio6_o	gpio5_o	gpio4_o	gpio3_o	gpio2_o	gpio1_o
TYPE	r/w		r/w		r/w		r/w		r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w
RESET	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0

0x0380

Table 4-15. Register 0C Description

Name	Description	Operation
Bits 15-14	**gpio567_drv[1:0]**— These bits select output drive strength for GPIO5 through GPIO7.	00 (default) = lowest drive strength; 11 = highest drive strength.
Bits 13-12	**miso_drv[1:0]**- These bits select output drive strength for signal MISO.	00 (default) = lowest drive strength; 11 = highest drive strength.
Bits 11-10	**clko_drv[1:0]**- These bits select output drive strength for signal CLKO.	00 (default) = lowest drive strength; 11 = highest drive strength.
Bits 9-8	**irqb_drv[1:0]**- These bits select output drive strength for signal $\overline{\text{IRQ}}$.	00 (default) = lowest drive strength; 11 = highest drive strength.

Table 4-15. Register 0C Description (continued)

Name	Description	Operation
Bit 7	**irqb_pup_en** — $\overline{\text{IRQ}}$ pullup enable.	1 = Onboard pullup enabled (nominal 40 kΩ) on $\overline{\text{IRQ}}$ pin (default) 0 = Open drain only (external pullup required).
Bit 6	**gpio7_o** — GPIO7 output value.	1 = GPIO7 driven high 0 = GPIO7 driven low
Bit 5	**gpio6_o** — GPIO6 output value.	1 = GPIO6 driven high 0 = GPIO6 driven low
Bit 4	**gpio5_o** — GPIO5 output value.	1 = GPIO5 driven high 0 = GPIO5 driven low
Bit 3	**gpio4_o** — GPIO4 output value.	1 = GPIO4 driven high 0 = GPIO4 driven low
Bit 2	**gpio3_o** — GPIO3 output value.	1 = GPIO3 driven high 0 = GPIO3 driven low
Bit 1	**gpio2_o** — GPIO2 output value.	1 = GPIO2 driven high 0 = GPIO2 driven low
Bit 0	**gpio1_o** — GPIO1 output value.	1 = GPIO1 driven high 0 = GPIO1 driven low

4.16 LO1_Int_Div - Register 0F

The LO1_Int_Div Register 0F contains the 8-bit integer divide value for the LO1 fractional-N synthesizer that sets transceiver channel frequency. See Table 4-18.

Register 0F 0x0F

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									lo1_idiv[7:0]							
TYPE	r/w															
RESET	0	0	0	0	1	1	1	1	1	0	0	1	0	1	0	1

0x0F95

Table 4-16. Register 0F Description

Name	Description	Operation
Bits 15-8	Reserved.	Leave default.
Bits 7-0	**lo1_idiv[7:0]** — The LO1 integer divide bits represent the integer divide value for the LO1 fractional-N synthesizer.	Default is 149dec (0x95). See Table 4-18.

4.17 LO1_Num - Register 10

The LO1_Num Register 10 contains the 16-bit integer numerator value for the LO1 fractional-N synthesizer that sets transceiver channel frequency. See Table 4-18.

Register 10 0x10

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	lo1_num[15:0]															
TYPE	r/w															
RESET	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	0x5000															

Table 4-17. Register 10 Description

Name	Description	Operation
Bits 15-0	**lo1_num[15:0]** — These bits represent the numerator of the fractional divide value for the LO1 fractional-N synthesizer.	Default is 20,480dec (0x5000). See Table 4-18.

Table 4-18. Channel Operation

Channel (Dec)	802.15.4 Channel Number	Frequency (MHz)	Integer Setting lo1_idiv[7:0] (Dec / Hex)	Fractional Setting lo1_num[15:0] (Dec / Hex)
1	11	2405	149 / 0x95 (default)	20480 / 0x5000 (default)
2	12	2410	149 / 0x95	40960 / 0xA000
3	13	2415	149 / 0x95	61440 / 0xF000
4	14	2420	150 / 0x96	16384 / 0x4000
5	15	2425	150 / 0x96	36864 / 0x9000
6	16	2430	150 / 0x96	57344 / 0xE000
7	17	2435	151 / 0x97	12288 / 0x3000
8	18	2440	151 / 0x97	32768 / 0x8000
9	19	2445	151 / 0x97	53248 / 0xD000
10	20	2450	152 / 0x98	8192 / 0x2000
11	21	2455	152 / 0x98	28672 / 0x7000
12	22	2460	152 / 0x98	49152 / 0xC000
13	23	2465	153 / 0x99	4096 / 0x1000
14	24	2470	153 / 0x99	24576 / 0x6000
15	25	2475	153 / 0x99	45056 / 0xB000
16	26	2480	154 / 0x9A	0 / 0x0000

4.18 PA_Lvl - Register 12

The PA_Lvl Register 12 sets the power level and drive level of the transmitter power amplifier. See Table 6-3 for power level versus field settings. The PA_Lvl register initiates to nominal PA power and drive set for 0 dBm typical.

Register 12 0x12

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									pa_lvl_coarse[1:0]		pa_lvl_fine[1:0]		pa_drv_coarse[1:0]		pa_drv_fine[1:0]	
TYPE									r/w		r/w					
RESET	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0

0x00BC

Table 4-19. Register 12 Description

Name	Description	Operation
Bits 15-8	Reserved	Leave default
Bits 7-6	**pa_lvl_coarse[1:0]** - These bits select the coarse PA power level adjustment.	See Section 6.4.1, "Transmit Power Adjustment for more information.
Bits 5-4	**pa_lvl_fine[1:0]** - These bits selects fine PA power level adjustment.	See Section 6.4.1, "Transmit Power Adjustment for more information.
Bits 3-2	pa_drv_coarse[1:0] - These bits select the coarse PA drive level adjustment.	See Section 6.4.1, "Transmit Power Adjustment for more information.
Bits 1-0	**pa_drv_fine[1:0]** - These bits select the fine PA drive level adjustment	See Section 6.4.1, "Transmit Power Adjustment for more information.

4.19 Tmr_Cmp1_A - Register 1B

The Tmr_Cmp1_A Register 1B contains the disable bit for Timer Comparator 1 and stores the most significant 8 bits of the 24-bit compare value (the lower 16 bits of the compare value are stored in Tmr_CMP1_B Register 1C). With regard to using the timer comparator:

- It is suggested that the timer be disabled (writing tmr_cmp1_dis to 1) during system initialization as the default mode out of reset is timer enabled.
- The value in Register 1B will not be loaded in the comparator and the affect of the timer disable bit will not active until Register 1C is written. The 24-bit comparator value must be loaded into the comparator register in parallel, and as a result, the load is caused by a write Register 1C.

Writing of Registers 1B and 1C can be done as a recursive SPI register write transaction or two separate singular transactions. Writing to Register 1C as a separate operation will always use the present value of Register 1B to load the comparator value and set the state of the disable bit.

Register 1B 0x1B

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tmr_cmp1_dis								tmr_cmp1[23:16]							
TYPE	r/w								r/w							
RESET	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	0x00FF															

Table 4-20. Register 1B Description

Name	Description	Operation
Bits 14-8	Reserved	Leave default
Bit 15	**tmr_cmp1_dis** — This bit disables the Event Timer Comparator 1 function.	1 = Disables the Event Timer Compare 1 function. 0 = Enables the Event Timer Compare 1 function (default).
Bits 7-0	**tmr_cmp1[23:16]** — These bits represent the 8 most significant bits of 24-bit Event Timer 1 absolute time compare value, tmr_cmp1[23:0].	Default is 0xFF.

4.20 Tmr_Cmp1_B - Register 1C

The Tmr_CMP1_B Register 1C stores the least significant 16 bits of the 24-bit compare value. Writing to Register 1C causes an internal load of the full 24-bit comparator value (see Section 4.19, “Tmr_Cmp1_A - Register 1B) and activates the mode presently set into the tmr_cmp1_dis control bite.

Register 1C 0x1C

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tmr_cmp1[15:0]															
TYPE	r/w															
RESET	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0xFFFF															

Table 4-21. Register 1C Description

Name	Description	Operation
Bits 15-0	**tmr_cmp1[15:0]** — These bits represent the 16 least significant bits of 24-bit Event Timer 1 absolute time compare value, tmr_cmp1[23:0].	Default is 0xFFFF.

4.21 Tmr_Cmp2_A - Register 1D

The Tmr_Cmp2_A Register 1B contains the disable bit for Timer Comparator 2 and stores the most significant 8 bits of the 24-bit compare value (the lower 16 bits of the compare value are stored in Tmr_CMP2_B Register 1E). With regard to using the timer comparator:

- It is suggested that the timer be disabled (writing tmr_cmp2_dis to 1) during system initialization as the default mode out of reset is timer enabled.
- The value in Register 1D will not be loaded in the comparator and the affect of the timer disable bit will not active until Register 1E is written. The 24-bit comparator value must be loaded into the comparator register in parallel, and as a result, the load is caused by a write Register 1E.

Writing of Registers 1D and 1E can be done as a recursive SPI register write transaction or two separate singular transactions. Writing to Register 1E as a separate operation will always use the present value of Register 1D to load the comparator value and set the state of the disable bit.

Register 1D 0x1D

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tmr_cmp2_dis								tmr_cmp2[23:16]							
TYPE	r/w								r/w							
RESET	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	0x00FF															

Table 4-22. Register 1D Description

Name	Description	Operation
Bits 14-8	Reserved	Leave default
Bit 15	**tmr_cmp2_dis** — This bit disables the Event Timer Comparator 2.	1 = Disables the Event Timer Compare 2 function. 0 = Enables the Event Timer Compare 2 function (default).
Bits 7-0	**tmr_cmp2[23:16]** — These bits represent the 8 most significant bits of 24-bit Event Timer 2 absolute time compare value, tmr_cmp2[23:0].	Default is 0xFF.

4.22 Tmr_Cmp2_B - Register 1E

The Tmr_CMP2_B Register 1E stores the least significant 16 bits of the 24-bit compare value. Writing to Register 1E causes an internal load of the full 24-bit comparator value (see Section 4.21, “Tmr_Cmp2_A - Register 1D) and activates the mode presently set into the tmr_cmp2_dis control bit.

Register 1E 0x1E

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	tmr_cmp2[15:0]															
TYPE	r/w															
RESET	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0xFFFF															

Table 4-23. Register 1E Description

Name	Description	Operation
Bits 15-0	**tmr_cmp2[15:0]** — These bits represent the 16 least significant bits of 24-bit Event Timer 2 absolute time compare value, tmr_cmp2[23:0].	Default is 0xFFFF.

4.23 IRQ_Status - Register 24

The IRQ_Status Register 24 contains status bits that can, in turn, cause an interrupt request when enabled. Reading the register clears the status bits and releases an associated interrupt request on $\overline{\text{IRQ}}$. Note use of interrupt status Bit 14, Bit 13, Bit 7 and Bit 6 which are multiplexed and have special functionality.

Register 24 0x24

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	pll_lock_irq	ram_addr_err	arb_busy_err			attn_irq	doze_irq	tmr1_irq	rx_rcvd_irq	tx_sent_irq	cca_irq			tmr2_irq	cca	crc_valid
TYPE	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0x0000

Table 4-24. Register 24 Description

Name	Description	Operation
Bits 12-11, 4-3	Reserved	Leave default
Bit 15	**pll_lock_irq** — The Local Oscillator 1 Lock Detect Interrupt bit indicates whether the LO1 PLL is in or out of lock.	1 = LO1 PLL out of lock. Will cause an interrupt if pll_lock_mask is enabled. 0 = LO1 PLL is locked.
Bit 14	**ram_addr_err or tx_done_irq** — The Packet RAM Address Error Interrupt or Stream Mode TX Done Interrupt bit is a multiplexed interrupt status bit.	When SPI bit use_strm_mode, Register 7, Bit 5 = 0, Register 24, Bit 14 represents 'ram_addr_err'. ram_addr_err definition: a recursive SPI read or write operation to Packet RAM exceeded maximum RAM address. When SPI bit use_strm_mode, Register 7, Bit 5 = 1, Register 24, Bit 14 represents 'tx_done_irq'. tx_done_irq definition: TX Stream Mode reception complete and transceiver has returned to Idle.
Bit 13	**arb_busy_err or rx_done_irq** — The Packet RAM Arbiter Busy Error Interrupt or Steam Mode RX Done Interrupt bit is a multiplexed interrupt status bit.	When SPI bit use_strm_mode, Register 7, Bit 5 = 0, Register 24, Bit 13 represents 'arb_busy_err'. arb_busy_err definition: a SPI read or write operation to Packet RAM attempted during packet reception or transmission, respectively. When SPI bit use_strm_mode, Register 7, Bit 5 = 1, Register 24, Bit 13 represents 'rx_done_irq'. rx_done_irq definition: RX Stream Mode reception complete and transceiver has returned to Idle Mode.
Bit 10	**attn_irq** — The Attention Interrupt bit indicates the $\overline{\text{ATTN}}$ pin has been asserted or Power-up complete condition from a reset condition.	The bit being set indicates the $\overline{\text{ATTN}}$ signal has been asserted low or that the MC13201 has reached a Power-up complete condition after software reset (CE released) or a hardware reset (RST released).

Table 4-24. Register 24 Description (continued)

Name	Description	Operation
Bit 9	**doze_irq** — The Doze Timer Interrupt bit.	This bit gets set when the ‘tmr_cmp2[23:0]’ field matches the current Event Timer value while in Doze Mode. The MC13201 returns to Idle state from Doze Mode.
Bit 8	**tmr1_irq** — The Timer Compare 1 Interrupt bit.	This bit gets set when the ‘tmr_cmp1[23:0]’ field matches the current Event Timer value.
Bit 7	**rx_ rcvd_irq or rx_strm_irq** — The RX Packet Received Interrupt or RX Stream Data Ready Interrupt bit is a multiplexed interrupt status bit	When SPI bit use_strm_mode, Register 7, Bit 5 = 0, Register 24, Bit 7 represents ‘rx_rcvd_irq’. rx_rcvd_irq definition: RX Packet Mode reception complete and transceiver has returned to Idle Mode. When SPI bit use_strm_mode, Register 7, Bit 5 = 1, Register 24, Bit 7 represents ‘rx_strm_irq’. rx_strm_irq definition: 1) First occurrence - RX Packet Length is available to be read. 2) Subsequent occurrences - next receive Stream data word is ready to be read.
Bit 6	**tx_ sent_irq or tx_strm_irq** — The TX Packet Sent Interrupt or TX Stream Data Needed Interrupt bit is a multiplexed interrupt status bit.	When SPI bit use_strm_mode, Register 7, Bit 5 = 0, Register 24, Bit 6 represents ‘tx_sent_irq’. tx_sent_irq definition: TX Packet Mode operation complete and transceiver has returned to Idle Mode. When SPI bit use_strm_mode, Register 7, Bit 5 = 1, Register 24, Bit 7 represents ‘tx_strm_irq’. tx_strm_irq definition: Transceiver is ready for next Stream transmit data word to be written.
Bit 5	**cca_irq** — The Clear Channel Assessment Ready Interrupt bit.	This bit is set when the ‘Clear Channel Assessment’ operation is complete.
Bit 2	**tmr2_irq** — The Timer Compare 2 Interrupt bit.	This bit gets set when the ‘tmr_cmp2[23:0]’ field matches the current Event Timer value, or alternately if ‘tc2_prime[15:0]’ field matches the current Event Timer[15:0] when enabled.
Bit 1	**cca** — The Clear Channel Assessment bit indicates channel busy or channel idle.	1 = channel busy detected 0 = channel idle detected **Note:** For cca_type[1:0], Register 6, Bits 5:4 = 10, Energy Detect Mode, CCA is not calculated and cca is held low.
Bit 0	**crc_valid** — The RX CRC Result bit denotes if the CRC is correct or not.	1 = RX CRC correct 0 = RX CRC incorrect (default)

4.24 RST_Ind - Register 25

The RST_Ind Register 25 contains the reset indicator bit. Bit reset_ind is cleared during a reset and gets set if Register 25 is read after a reset and remains set. This bit is useful for the MCU to determine if the transceiver has returned from a Hibernate condition via an $\overline{\text{ATTN}}$ signal or recovered from a reset condition.

Register 25 0x25

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									reset_ind							
TYPE					r				r				r			
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
									0x0000							

Table 4-25. Register 25 Description

Name	Description	Operation
Bits 15-8, 6-0	Reserved	
Bit 7	**reset_ind** — The reset indicator bit shows whether Register 25 was read since the last $\overline{\text{RST}}$ assertion or program reset.	1 = Register 25 has been read since the last $\overline{\text{RST}}$ or Program Reset event. 0 = Register 25 has not been read since the last $\overline{\text{RST}}$ or Program Reset event. Note: Reading Register 25 will set Bit 7.

4.25 Current_Time_A - Register 26

The Current_Time_A Register 26 is read to get the 8 most significant bits of the current value of the 24-bit counter of the Event Timer.

Register 26 0x26

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									et[23:16]							
TYPE									r							
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
									0x0000							

Table 4-26. Register 26 Description

Name	Description	Operation
Bits 15-8	Reserved	
Bits 7 - 0	**et [23:16]**— These bits are the 8 most significant bits of the current time in the Event Timer counter.	

4.26 Current_Time_B - Register 27

The Current_Time_B Register 27 is read to get the 16 least significant bits of the current value of the 24-bit counter of the Event Timer.

Register 27 0x27

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	et[15:0]															
TYPE	r															
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0x0000															

Table 4-27. Register 27 Description

Name	Description	Operation
Bits 15-0	**et[15:0]** — These bits represent the 16 least significant bits of the current time of the Event Timer counter.	

4.27 GPIO_Data_In - Register 28

The GPIO_Data_In Register 28 is read to determine the state of any GPIO that are configured as an input.

Register 28 0x28

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
		gpio7_i	gpio6_i	gpio5_i	gpio4_i	gpio3_i	gpio2_i	gpio1_i								
TYPE		r	r	r	r	r	r	r								
RESET		x	x	x	x	x	x	x								
	Unknown from reset															

Table 4-28. Register 28 Description

Name	Description	Operation
Bits 15, 7-0	Reserved	
Bit 14	**gpio7_i** — This bit is the input value of GPIO7.	With gpio7_oen = 0 and gpio7_ien = 1; GPIO7 is configured as an input whose value can be read from gpio7_i.
Bit 13	**gpio6_i** — This bit is the input value of GPIO6.	With gpio6_oen = 0 and gpio6_ien = 1; GPIO6 is configured as an input whose value can be read from gpio6_i.
Bit 12	**gpio5_i** — This bit is the input value of GPIO5.	With gpio5_oen = 0 and gpio5_ien = 1; GPIO5 is configured as an input whose value can be read from gpio5_i.

Table 4-28. Register 28 Description

Name	Description	Operation
Bit 11	**gpio4_i** — This bit is the input value of GPIO4.	With gpio4_oen = 0 and gpio4_ien = 1; GPIO4 is configured as an input whose value can be read from gpio4_i.
Bit 10	**gpio3_i** — This bit is the input value of GPIO3.	With gpio3_oen = 0 and gpio3_ien = 1; GPIO3 is configured as an input whose value can be read from gpio3_i.
Bit 9	**gpio2_i** — This bit is the input value of GPIO2.	With gpio2_oen = 0 and gpio2_ien = 1; GPIO2 is configured as an input whose value can be read from gpio2_i.
Bit 8	**gpio1_i** — This bit is the input value of GPIO1.	With gpio1_oen = 0 and gpio1_ien = 1; GPIO1 is configured as an input whose value can be read from gpio1_i.

4.28 Chip_ID - Register 2C

The Chip_ID Register 2C is read to get the 9-bit chip version code contained in the chip_id[8:0] field. Valid version numbers include:

- 0x6000
- 0x6400
- 0x6800 (latest version)

NOTE

> The latest version of the MC13201 uses transceiver Chip_ID 0x6800. This device must have Modem SPI Registers 0x31 and 0x34 initialized (over-programmed) from default conditions for proper transceiver operation. See Section 4.1, “Overview and the individual register descriptions.

Register 2C 0x2C

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	chip_id[8:0]															
TYPE	r															
RESET	0	1	1	0	0	X	0	0	0	0	0	0	0	0	0	0

0x6000 or 0x6400

Table 4-29. Register 2C Description

Name	Description	Operation
Bits 6-0	Reserved	
Bits 15- 7	**chip_id [8:0]**— These bits are the 9-bit chip version code for the transceiver.	Version dependent.

4.29 RX_Status - Register 2D

The RX_Status Register 2D has two fields, the first of which represents the average results of the CCA algorithm selected by cca_type[1:0], Register 6, Bits 5-4. The second field gives the receive packet length parsed from the packet header; the value is latched after an RX Start Frame Delimiter is detected.

During a RX Stream Mode sequence, loading a valid FLI in rx_pkt_latch[6:0] causes the first rx_strm_irq status and interrupt in the sequence. Reading RX_Status Register 2D for that first rx_strm_irq interrupt will clear the status and the interrupt. As a result, reading IRQ_Status Register 24 is not required (see Section 6.3.3.3, "Packet Transmit Mode).

Register 2D 0x2D

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	cca_final[7:0]									rx_pkt_latch[6:0]						
TYPE	r									r						
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0x0000															

Table 4-30. Register 2D Description

Name	Description	Operation
Bit 7	Reserved	
Bits 15-8	**cca_final [7:0]** — Average CCA energy.	These bits represent the average result of the CCA algorithm selected by cca_type[1:0], Register 6, Bits 5-4.
Bits 6- 0	**rx_pkt_latch [6:0]** — RX packet length	These bits give the RX packet length parsed from the packet header. The value is latched when an RX Start Frame Delimiter is detected.

4.30 Timestamp_A - Register 2E

The Timestamp_A Register 2E stores the most significant 8 bits of the value in the Event Timer counter (et[23:0]) when the beginning of the most recent receive packet occurred. The value is latched immediately following reception of the FLI field and at the beginning of the payload data.

Register 2E 0x2E

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									timestamp[23:16]							
TYPE									r							
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0x0000															

Table 4-31. Register 2E Description

Name	Description	Operation
Bits 15-8	Reserved	
Bits 7 - 0	**timestamp [23:16]**— 8 most significant bits of the latched 24-bit timestamp value for the beginning of the receive packet.	

4.31 Timestamp_B - Register 2F

The Timestamp_B Register 2F stores the least significant 16 bits of the value in the Event Timer counter (et[23:0]) when the beginning of the most recent receive packet occurred. The value is latched immediately following reception of the FLI field and at the beginning of the payload data.

Register 2F 0x2F

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	timestamp[15:0]															
TYPE	r															
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0x0000															

Table 4-32. Register 2F Description

Name	Description	Operation
Bits 15-0	**timestamp[15:0]** — 16 least significant bits of the latched 24-bit timestamp value for the beginning of the receive packet.	

4.32 BER_Enable - Register 30

The BER_Enable Register 30 contains the bit error rate test enable bit which allows the transceiver to be put into continuous Receive or Transmit Mode. This feature is useful sequences in RF test configurations (reference application note AN2976). The default condition is with the Continuous Mode disabled.

Register 30 0x30

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	ber_en															
TYPE	r/w															
RESET	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	0x0004															

Table 4-33. Register 30 Description

Name	Description	Operation
Bits 14-0	Reserved	
Bit 15	**ber_en** — The bit error rate test enable bit allows the transceiver to be put into continuous Receive or Transmit Mode. Continuous TX Mode is useful for current measurements or for looking at TX spectrum. Continuous RX Mode is useful for looking at current.	1 = When a TX operation or RX operation is enabled, the transceiver stays in that operation until aborted. 0 = Continuous operation disabled; normal operation.

4.33 PSM_Mode - Register 31

The PSM_Mode Register 31 contains the phase shift modulator Test Mode field. The psm_tm[2:0] 3-bit field is only used in two modes:

- When psm_tm[2:0] = 0b000, there is normal TX modulation and normal operation.
- When psm_tm[2:0] = 0b001, the modulator is disabled and the transmitter puts out an unmodulated signal. When the unmodulated signal is combined with continuous TX operation (see BER_Enable Register 30), the unmodulated spectrum of the transmitter can be observed (see application note AN2976).
- Default is normal modulated operation.

NOTE

The PSM_Mode Register 31 must be over-written for proper transceiver operation for devices that read Chip_ID Register 2C as 0x6800 (See Section 4.28, “Chip_ID - Register 2C):

- For normal operation, the over-write value is 0xA0C0 (psm_tm[2:0] = 0b000).
- For test mode, the over-write value is 0xA0C8 (psm_tm[2:0] = 0b001).

Register 31 0x31

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
											psm_tm[2:0]					
TYPE												r/w				
RESET	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

0xA000

Table 4-34. Register 31 Description

Name	Description	Operation
Bits 15-6, 2-0	Reserved	
Bits 5-3	**psm_tm[2:0]** — Phase shift modulator Test Mode. Use only the two stated conditions.	psm_tm[2:0] = 0b000 - normal modulated operation. psm_tm[2:0] = 0b001 - modulator disabled.

4.34 Reserved - Register 34

The reserved Register 34 is listed only in that it must be over-written for latest devices.

NOTE

The reserved Register 34 must be over-written for proper transceiver operation for devices that read Chip_ID Register 2C as 0x6800 (See Section 4.28, “Chip_ID - Register 2C):

- Over-write value is 0xFEC6

Register 34 0x34

BIT	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPE	r	r	r	r	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w
RESET	1	1	1	1	1	1	1	0	1	1	0	0	0	0	1	0

0xFEC2

Table 4-35. Register 31 Description

Name	Description	Operation
Bits 15-0	Reserved	Default = 0xFEC2

Chapter 5
Serial Peripheral Interface (SPI)

5.1 Overview

Control of the MC13201 and data transfers are accomplished by means of a 4-wire Serial Peripheral Interface (SPI). The SPI port is a fully static design that requires no additional clocks besides SPICLK for accessing internal registers, although Packet RAM accesses do require the reference oscillator to be running. This allows for lower power when the SPI must stay alive while the rest of the device is in power-down.

Although the normal SPI protocol is based on 8-bit transfers, the MC13201 imposes a higher level transaction protocol that is based on multiple 8-bit transfers per transaction. In its simplest form, a singular SPI read or write transaction consists of an 8-bit header transfer followed by two 8-bit data transfers. The header denotes access type and register address. The following bytes are read or write data. The SPI also supports recursive 'data burst' transactions in which additional data transfers can occur. The recursive mode is primarily intended for Packet RAM access and fast configuration of the MC13201. Partial word accesses are not supported.

All SPI accessible registers are configured with 16-bit data width. The address range is 6 bits which allows for 64 locations although not all are implemented. Internal data RAMs are accessed as dedicated addresses within the register address field.

An additional feature is a software reset capability where a write to Address 00 will accomplish most of the equivalency of a hardware reset.

5.2 SPI Basic Operation

The MC13201 operates as a SPI Slave only. The host microcontroller supplies the interface clock and acts as SPI master.

5.2.1 SPI Pin Definition

The MC13201 SPI signals of CE, CPICLK, MOSI, and MISO are defined in the following paragraphs. A typical interconnection to a microcontroller is shown in Figure 5-1.

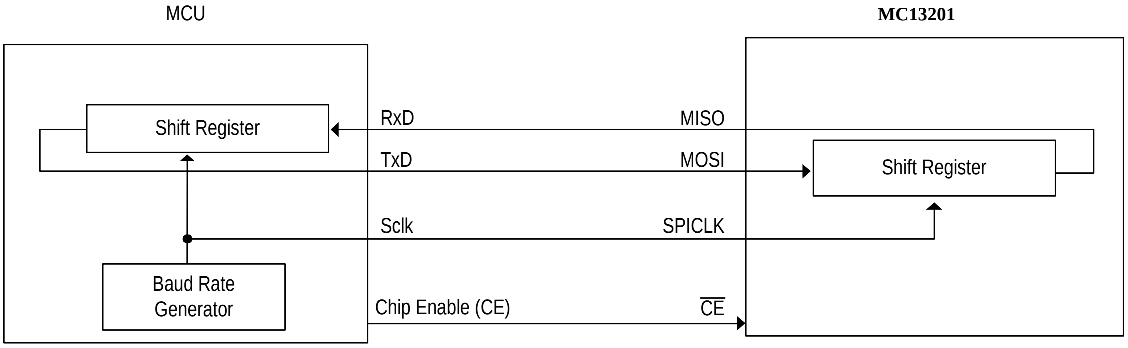


Figure 5-1. Typical SPI Connection with an MCU.

5.2.1.1 Chip Enable ($\overline{\text{CE}}$)

A transaction on the SPI port is framed by the active low Chip Enable ($\overline{\text{CE}}$) input signal which is driven by the host MCU. A transaction is a minimum of 3 SPI bursts and can extend to a greater number of bursts.

5.2.1.2 SPI Clock (SPICLK)

The host drives the SPI Clock (SPICLK) input to the MC13201. Data is clocked into the master or slave on the leading (rising) edge of the return-to-zero SPICLK and data out changes state on the trailing (falling) edge of SPICLK.

NOTE

For Freescale microcontrollers, the SPI clock format is the clock phase control bit CPHA = 0 and the clock polarity control bit CPOL = 0.

5.2.1.3 Master Out / Slave In (MOSI)

The Master Out/Slave In (MOSI) input presents incoming data from the host to the transceiver (slave input).

5.2.1.4 Master In / Slave Out (MISO)

The MC13201 presents data to the master on its MISO output. This output is user configurable for both drive strength and its off state.

5.2.1.4.1 Setting MISO Output Drive Strength

MISO output drive strength is programmed by writing to miso_drv[1:0], GPIO_Data_Out Register 0C. There are 4 levels of drive strength with field value 00 for lowest and value 11 for greatest. The default value is 00.

NOTE

It is suggested the user program MISO for greatest drive strength for best performance.

5.2.1.4.2 Setting MISO Off Impedance

MISO off impedance (output state when $\overline{\text{CE}}$ is negated or high) can be programmed by writing to miso_hiz_en, Control_B Register 07. Setting miso_hiz_en to “1” causes MISO to tri-state when $\overline{\text{CE}}$ is high, and this is the default state. MISO must tri-state when $\overline{\text{CE}}$ is negated if other slave devices share the host SPI bus.

Writing miso_hiz_en to “0” causes MISO to be active low when $\overline{\text{CE}}$ is negated. This condition can be used when the transceiver is the only SPI slave.

5.2.2 SPI Burst Operation

The SPI port of an MCU transfers data in bursts of 8 bits with most significant bit (MSB) first. The master (MCU) can send a byte to the slave (transceiver) on the MOSI line and the slave can send a byte to the master on the MISO line. Although an MC13201 transaction is three or more SPI bursts long, the timing of a single SPI burst is shown in Figure 5-2.

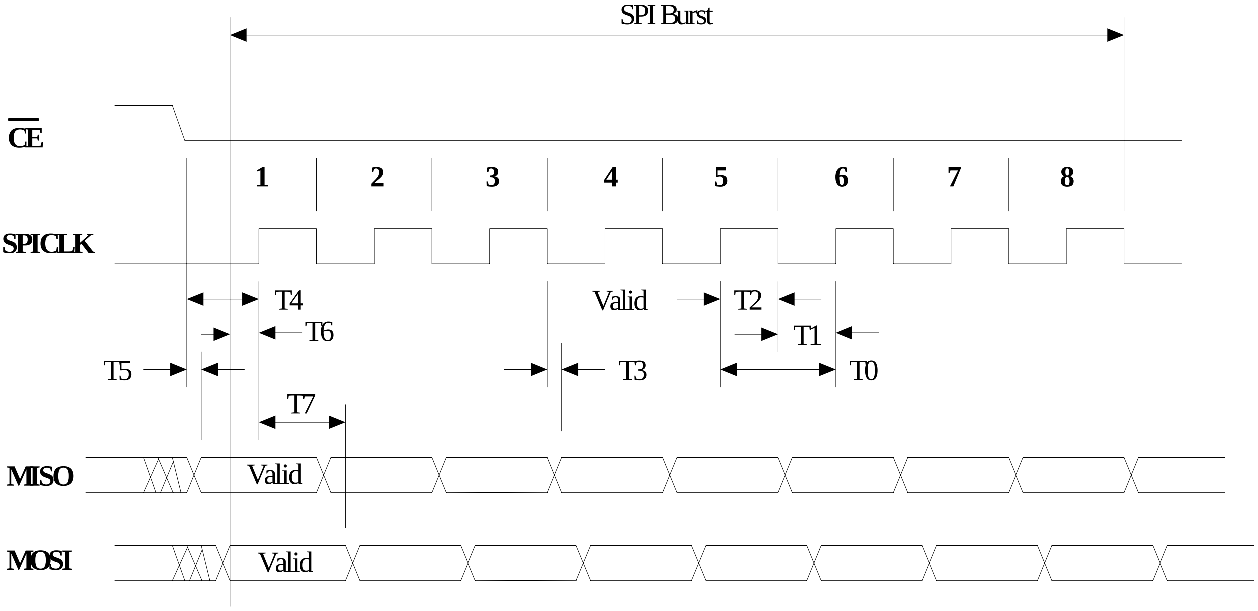


Figure 5-2. SPI Burst Timing Diagram

Table 5-1. SPI Timing Specifications

Symbol	Parameter	Min	Typ	Max	Unit
T0	SPICLK period	125			ns
T1	Pulse width, SPICLK low	50			ns
T2	Pulse width, SPICLK high	50			ns
T3	Delay time, MISO data valid from falling SPICLK		15		ns
T4	Setup time, $\overline{\text{CE}}$ low to rising SPICLK		15		ns

Table 5-1. SPI Timing Specifications (continued)

Symbol	Parameter	Min	Typ	Max	Unit
T5	Delay time, MISO valid from $\overline{\text{CE}}$ low		15		ns
T6	Setup time, MOSI valid to rising SPICLK		15		ns
T7	Hold time, MOSI valid from rising SPICLK		15		ns

5.3 SPI Singular Transactions

Although the SPI port of an MCU transfers data in bursts of 8 bits, the MC13201 requires that a complete SPI transaction be framed by $\overline{\text{CE}}$, and there will be 3 or more bursts per transaction. There are generally two classes of transactions, which are singular and recursive.

5.3.1 SPI Singular Transaction Signalling

The assertion of $\overline{\text{CE}}$ to low signals the start of a transaction. The first SPI burst is a write of an 8-bit header to the transceiver (MOSI is valid) that defines a 6-bit address of the internal resource being accessed and identifies the access as being a read or write operation. In this context, a write is data written to the MC13201 and a read is data written to the SPI master. The following SPI bursts will be either the write data (MOSI is valid) to the transceiver or read data from the transceiver (MISO is valid).

Although the SPI bus is capable of sending data simultaneously between master and slave, the MC13201 never uses this mode. The number of data bytes (payload) will always be 2 for a singular access. After the final SPI burst, $\overline{\text{CE}}$ is negated to high to signal the end of the transaction. Should a SPI programming attempt fail to provide the MC13201 with at least 24 rising SPICLK edges prior to $\overline{\text{CE}}$ negating, no register data will be changed.

Figure 5-3 shows a read access transaction.

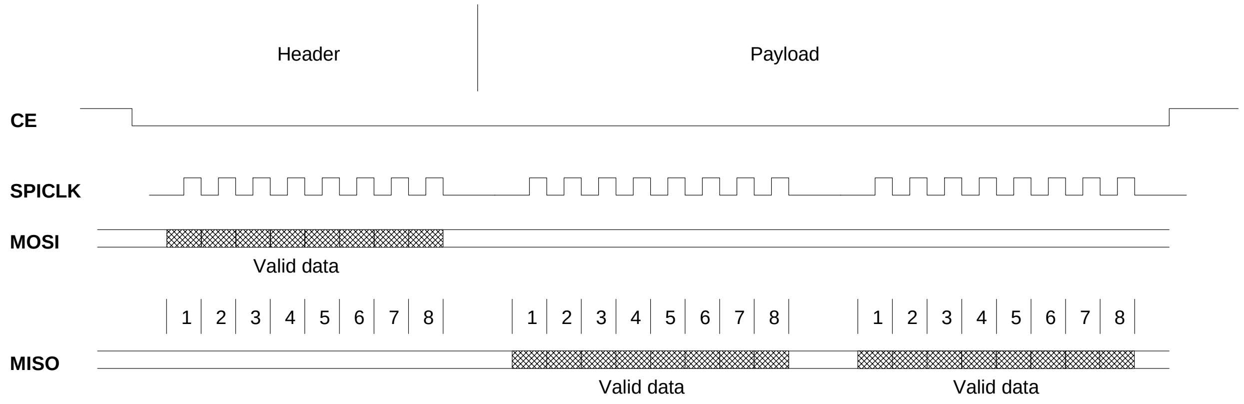


Figure 5-3. Singular Read Access

Figure 5-4 shows a write access transaction.

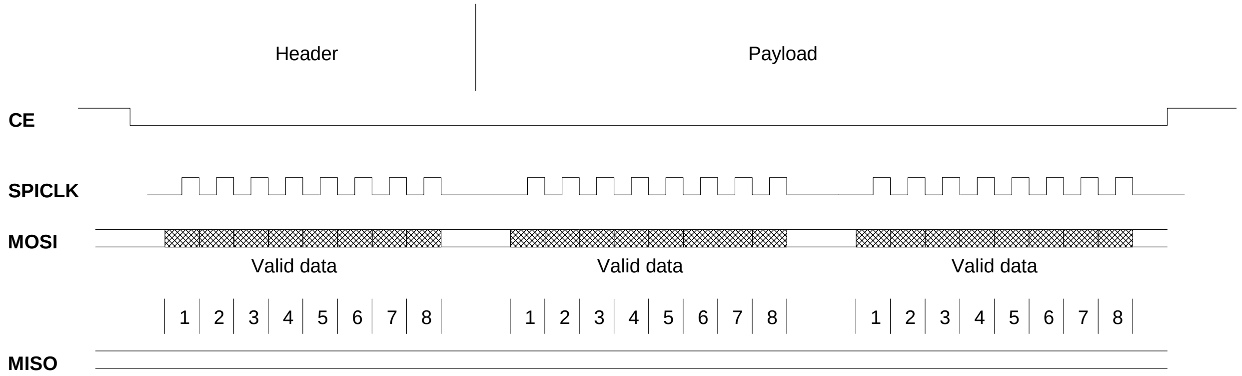


Figure 5-4. Singular Write Access

5.3.2 SPI Singular Transaction Protocol

R/$\overline{W}$	0	Addr 5	Addr 4	Addr 3	Addr 2	Addr 1	Addr 0	Data 15	Data 14	Data 13	Data 12	Data 11	Data 10	Data 9	Data 8	Data 7	Data 6	Data 5	Data 4	Data 3	Data 2	Data 1	Data 0
Header								Payload 1															

Figure 5-5. SPI Header and Payload Definition

A SPI transaction is divided into a header field and a payload. The header field is always 8 bits, while the payload data is in multiples of 2 bytes or 16 bits. A singular SPI transaction contains 24 bits of information. The header field contains a R/$\overline{W}$ bit and a 6-bit register address, as shown in Figure 5-5. The R/$\overline{W}$ bit identifies the transfer as a read (R/$\overline{W}$ =1) or write (R/$\overline{W}$ =0). The lower 6 bits in the header determines which of the 64 possible SPI locations is to be accessed for a read or write operation although not all possible addresses are implemented. The register address field also provides the starting address for a recursive read or write operation as described later.

The register data is presented MSB first.

5.4 Symbol / Data Format

When the transceiver receives 802.15.4 symbols, they are assembled as 4 symbols per 16-bit word. They are then presented to the RX Packet RAM or to the SPI directly as a 16-bit word. The ordering of symbols vs. word bit ordering is shown in Figure 5-6 which details the RX data flow through the device. The data is loaded into RX Packet RAM, and then sent to the SPI buffer. When the symbols are read via the SPI bus, 2 SPI bursts per 16-bit word are required and the MSB is presented first such that the symbols appear to the MCU in reverse order.

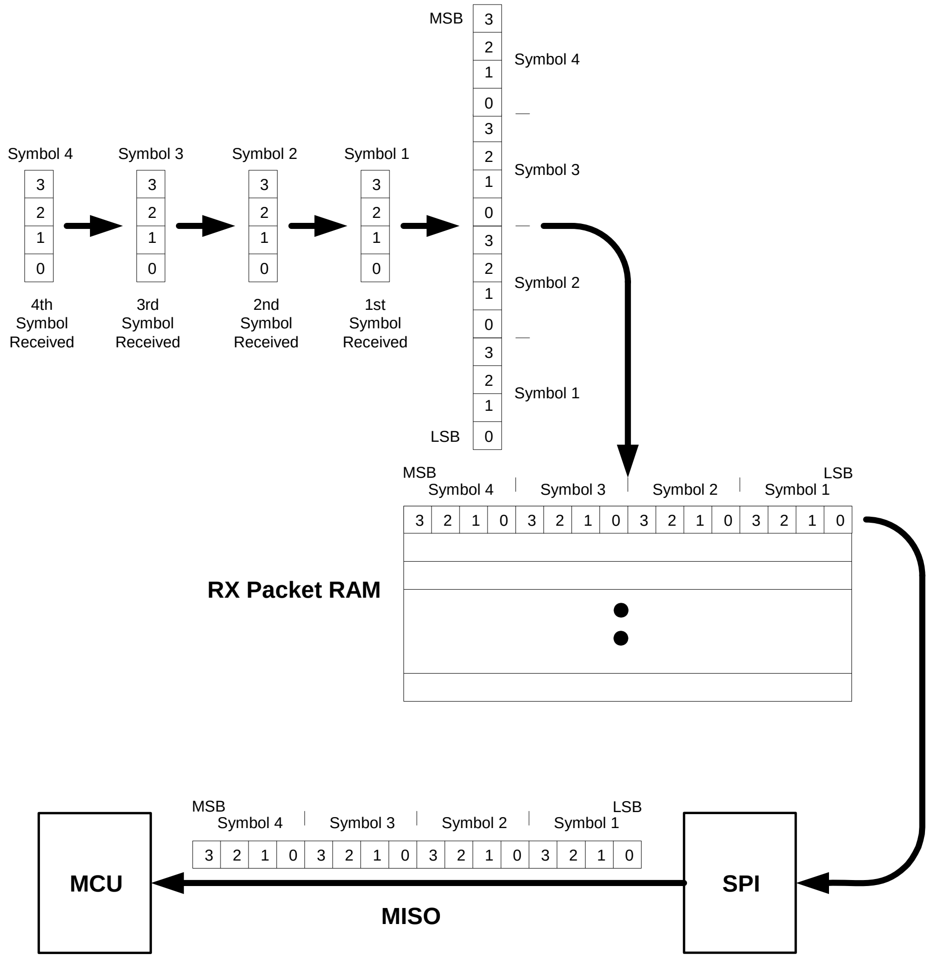


Figure 5-6. RX Symbol Flow Diagram

The inverse of the RX symbol / data flow is the case for TX data / symbols.

5.5 SPI Recursive Transactions

The MC13201 SPI also incorporates a recursive or ‘data burst’ transaction capability. This allows multiple sequential registers to be accessed with only one header field. Recursive reads and writes provide significant reduction in SPI overhead and a corresponding increase in programming speed.

1. The primary intent is for the software to be able to rapidly configure the MC13201.
2. Recursive reads and writes are convenient for accessing SPI register values which extend beyond the 16-bit SPI register format. Examples include writing Timer Comparator values (tmr_cmp1[23:0] through tmr_cmp4[23:0]) and reading the Time Stamp (timestamp[23:0]).
3. Recursive access capability enables the contents of Packet RAM to be read or written in an expedient manner.

5.5.1 Recursive SPI Register Read

Recursive register reads are invoked in an identical manner to singular read operations, however, by holding $\overline{\text{CE}}$ asserted for additional SPI bursts after the first 16-bit data payload is shifted out, the contents of the next SPI register address is made available on the MISO pin. An internal SPI register address pointer is automatically incremented during recursive reads to point to the next sequential SPI register location. For each subsequent set of 2 SPI bursts, SPICLK shifts out the contents of the next register address.

This sequence repeats as long as the $\overline{\text{CE}}$ is held asserted, allowing multiple sequential register contents of the SPI to be read starting at the header address. As the recursive read progresses, the SPI register address pointer continues to increment. When the address pointer reaches 63 decimal (the maximum implemented SPI register), the address pointer 'rolls over' to Address 03 and begins incrementing again. Address 03 is chosen to avoid the Program Reset function at Address 00 and the Rx Packet RAM and Tx Packet RAM at Addresses 01 and 02, respectively.

5.5.2 Recursive SPI Register Write

Recursive writes are invoked in an identical manner to singular write operations. But, by holding $\overline{\text{CE}}$ asserted for additional SPI bursts after the first 16-bit data payload is shifted in, the contents of the next SPI register address can be programmed. An internal SPI register address pointer is automatically incremented during recursive writes to point to the next higher sequential SPI register location. For each subsequent set of 2 SPI bursts, SPICLK shifts in the write data to the next register address.

This sequence repeats as long as the $\overline{\text{CE}}$ is held asserted, allowing multiple sequential register contents to be written starting at the header address. As the recursive write progresses, the SPI register address pointer continues to increment. When the address pointer reaches 63 decimal (the maximum implemented SPI register), the address pointer 'rolls over' to Address 03 and begins incrementing again. Address 3 is chosen to avoid the Program Reset function at Address 00 and the Rx Packet RAM and Tx Packet RAM at Addresses 01 and 02, respectively.

5.5.3 Special Case - Packet RAM Access

Packet RAM access is a special case access when the MC13201 is used in the Packet Mode. The MC13201 contains three embedded 128-byte 'Packet RAMs' used to facilitate reception and transmission of packet data. One RAM is dedicated for receive packet data and two are dedicated for transmit packet data. The Packet RAMs are configured in 64-word by 16-bit format and are both read and write accessible via the MC13201 SPI. The recursive data 'burst' access mode is used to efficiently access Packet RAM data.

Although the Packet RAMs are completely static, any RAM access requires the MC13201 to be in an active state; the reference clock circuit must be active. RAM read and write operations are prohibited while the device is in Hibernate or Doze mode.

Reading and writing the MC13201 Packet RAMs is accomplished by SPI burst accesses to dedicated Packet RAM register addresses within the register map. The RX_Pkt_RAM Register 01 is mapped to the Rx Packet RAM, and TX_Pkt_RAM Register 02 is mapped to the Tx Packet RAMs (choice is selected by the tx_ram2_select bit TX_Pkt_Ctl Register 03, Bit 15). The 16-bit data payload of the SPI access maps directly to the 16-bit word in the Packet RAM.

5.5.3.1 Recursive Receive Packet RAM Read Access

The receive Packet RAM is normally accessed when the MC13201 is in packet data mode and a valid frame has been received (as indicated by rx_rcvd_irq and crc_valid). The number of receive data bytes in the queue is shown by the rx_pkt_latch[6:0] field (this includes the full payload with the 2 CRC bytes).

The data is read by accessing RX_Pkt_RAM Register 01 with a recursive read. When accessing RX_Pkt_RAM Register 01, the SPI register address pointer is NOT incremented, instead, the Packet RAM read address pointer is incremented. Therefore, by using a recursive read, up to 64 words of packet memory can be read from the SPI with an access that requires but a single header field. A read access to Packet RAM always starts at the bottom of the RAM, i.e., the read address pointer always starts at the beginning of the data for a given read.

5.5.3.1.1 Receive Packet RAM Read Access Flow

Once receive data has been determined to be in Packet RAM, the following is a typical flow to read access the data:

1. Read rx_pkt_latch[6:0] to determine the number of payload bytes in receive Packet RAM. Note that this number includes 2 CRC bytes.
2. Calculate the number of SPI bursts that are required to access the Rx packet data, noting the following:
   a) The CRC is not normally accessed, so the number of bytes is reduced by 2.

      NOTE

      If the 2-byte CRC data is read. The byte order is reversed (last CRC byte is read first).

   b) All data read during an access must be done on 16-bit or 2-byte boundaries. Therefore, for an odd number of bytes, the byte count must be rounded up to an even number.
   c) The first word (or 2 bytes) read during a Packet RAM read should be discarded as the internal Packet RAM address is not accessed for the first word read operation. This has the effect of adding 2 bytes to the byte count.
3. Do a recursive SPI read transaction where:
   a) MCU asserts $\overline{\text{CE}}$ low.
   b) MCU sends the MC13201 the first SPI burst with header field of R/$\overline{\text{W}}$ bit = 1 and address field Addr[5:0] = 0x01 for the RX_Pkt_RAM register address.
   c) MCU reads MC13201 data with the number of SPI byte bursts as calculated in Number 2 above. Note that the first two bytes read from the MC13201 are discarded and that the number of SPI read bursts must be an even number. For an odd number of bytes, the one byte is also discarded.
   d) MCU negates $\overline{\text{CE}}$ high.

5.5.3.1.2 Receive Packet RAM Read Access Error Conditions

Two types of errors can occur during a Packet RAM read:

1. RAM address error - if the recursive read access exceeds 64 words (128 SPI data bursts), the internal read address counter will exceed the RAM address and generate an error indication via status bit ram_addr_err, IRQ_Status Register 24, Bit 14. An interrupt request can be generated with the error status by setting mask bit ram_addr_mask, IRQ_Mask Register 5, Bit 12. As with other interrupt requests, the status is cleared by reading the IRQ_Status register.
2. RAM arbitration busy - if the transceiver internal logic attempts to access the RAM during a SPI read access (a SPI read during an active Rx sequence), an error indication will be generated via status bit arb_busy_err, IRQ_Status Register 24, Bit 13. An interrupt request can be generated with the error status by setting mask bit arb_busy_mask, IRQ_Mask Register 5, Bit 11. As with other interrupt requests, the status is cleared by reading the IRQ_Status register.

5.5.3.2 Recursive Transmit Packet RAM Write Access

The transmit Packet RAM is normally accessed when the MC13201 is in packet data mode and a frame is to be transmitted. The number of transmit data bytes in the transmit queue is loaded into the tx_pkt_length[6:0] field (this represents the full payload which includes the data bytes stored in the transmit Packet RAM plus the 2 CRC bytes).

The data is written to the TX_Pkt_RAM Register 02 with a recursive access. When accessing TX_Pkt_RAM Register 02, the SPI register address pointer is NOT incremented, instead, the Packet RAM write address pointer is incremented. Therefore, by using a recursive write, up to 64 words of packet memory can be written via the SPI with an access that requires but a single header field. A write access to Packet RAM always starts at the bottom of the RAM, i.e., the write address pointer always starts at the beginning of the data for a given write.

5.5.3.2.1 Transmit Packet RAM Write Access Flow

Before data is actually written to the Tx Packet RAM, the Tx payload length must be written into field tx_pkt_length[6:0], TX_Pkt_Ctl Register 03, Bit 6 - 0. The maximum length is 127 bytes and is the number of actual payload bytes transmitted which includes 2 CRC bytes. The CRC bytes transmitted are generated by the transceiver hardware and are not loaded into the Packet RAM.

The following is a typical flow to write data to the Packet RAM:

1. Determine which of the two Transmit Packet RAMs are to be used - If Transmit Packet RAM2 is to be used, set status bit tx_ram2_select, TX_Pkt_Ctl Register 03, Bit 15. The default is Transmit Packet RAM1 selected. The tx_ram2_select status determines which transmit Packet RAM is accessed by an SPI transaction as well as which RAM is used during transmit mode.
2. Calculate the number of SPI bursts that are required to write the Tx packet data, noting the following:
   a) The CRC bytes are not written to Transmit Packet RAM.
   b) The maximum number of Tx packet data bytes is 125.

   c) All data written during an access must be done on 16-bit or 2-byte boundaries. Therefore, for an odd number of bytes, the byte count must be rounded up to an even number and an extra dummy byte will be written.

3. Do a recursive SPI write transaction where:
   a) MCU asserts $\overline{\text{CE}}$ low.
   b) MCU sends the MC13201 the first SPI burst with header field of R/$\overline{\text{W}}$ bit = 0 and address field Addr[5:0] = 0x02 for the TX_Pkt_RAM register address.
   c) MCU writes the MC13201 data with the number of SPI byte bursts as calculated in Step 2. The number of SPI write bursts must be an even number.
   d) MCU negates $\overline{\text{CE}}$ high.

5.5.3.2.2 Transmit Packet RAM Write Access Error Conditions

Two types of errors can occur during a Packet RAM write:

1. RAM address error - This can occur during software development and debug. If the recursive write access exceeds 64 words (128 SPI data bursts), the internal read address counter will exceed the RAM address and generate an error indication via status bit ram_addr_err, IRQ_Status Register 24, Bit 14. An interrupt request can be generated with the error status by setting mask bit ram_addr_mask, IRQ_Mask Register 5, Bit 12. As with other interrupt requests, the status is cleared by reading the IRQ_Status register.
2. RAM arbitration busy - if the transceiver internal logic attempts to access the RAM during an SPI write access (an SPI access during an active Tx sequence), an error indication will be generated via status bit arb_busy_err, IRQ_Status Register 24, Bit 13. An interrupt request can be generated with the error status by setting mask bit arb_busy_mask, IRQ_Mask Register 5, Bit 11. As with other interrupt requests, the status is cleared by reading the IRQ_Status register.

5.6 Program Reset (Writing Address 0x00)

A special access is a software reset capability known as a “Software Reset”. When R/$\overline{\text{W}}$ Register Address 0x00 is written, an internal chip reset of the digital core is generated. All synchronous logic in the MC13201 digital core is reset and the SPI register fields are returned to their default values. This Software Reset has the same effect on the MC13201 digital core as asserting the external $\overline{\text{RST}}$ pin except RAM contents are retained.

The Software Reset asserts internally as soon as the 8-bit header field containing Address 0 is shifted into the MOSI pin and a write operation is specified. The Software Reset remains asserted internally until the $\overline{\text{CE}}$ pin is negated. Reading from Register 00 does not generate a reset.

Chapter 6
Modes of Operation

6.1 Operational Modes Summary

The MC13201 has a number of passive operational modes that allow for low-current operation as well as modes where the transceiver is active. These modes are summarized, along with the transition times, in Table 6-1. Figure 6-1, Figure 6-2, Figure 6-3 and Figure 6-4 show the state diagrams for different operational modes.

Table 6-1. MC13201 Mode Definitions and Transition Times

Mode	Definition	Transition Time
Off	$\overline{\text{RST}}$ asserted. All IC functions Off, Leakage only. Digital outputs are tri-stated including IRQ. Any RAM buffer data is lost.	10 - 25 ms to Idle
Hibernate	Crystal Reference Oscillator Off. SPI not functional. IC Responds to $\overline{\text{ATTN}}$. Data is retained.	8 - 20 ms to Idle
Doze	Crystal Reference Oscillator On but CLKO is available only if Register 7, Bit 9 = 1 for frequencies of 1 MHz or less. (SPI not functional.) Responds to $\overline{\text{ATTN}}$ and can be programmed to enter Idle Mode through an internal timer comparator.	(300+1/CLKO) µs to Idle
Idle	Crystal Reference Oscillator On with CLKO output available. SPI active.	
Receive	Crystal Reference Oscillator On. Receiver On.	144 µs from Idle
Transmit	Crystal Reference Oscillator On. Transmitter On.	144 µs from Idle
CCA / Energy Detect	Crystal Reference Oscillator On. Receiver On.	144 µs from Idle

Idle mode is normally the state from which other states are derived. Low power states include the Off, Hibernate, and Doze modes. The Off state is the lowest power and is caused by the hardware reset. Transition from the Off to Idle mode occurs when $\overline{\text{RST}}$ is negated to high. Once in Idle mode, the SPI is active and used to control the MC13201. Transition to Hibernate or Doze modes is enabled via the SPI.

There are active states of Idle, Transmit (TX), Receive (RX), and Clear Channel Assessment (CCA) modes. The transition from the Idle state to the TX or RX is caused by writing to the xcvr_seq field. Packet RX and TX can also be modified as timer-based sequences using Tmr_Cmp2. Figure 6-1 shows state diagrams transceiver operations without timer-initiated sequences.

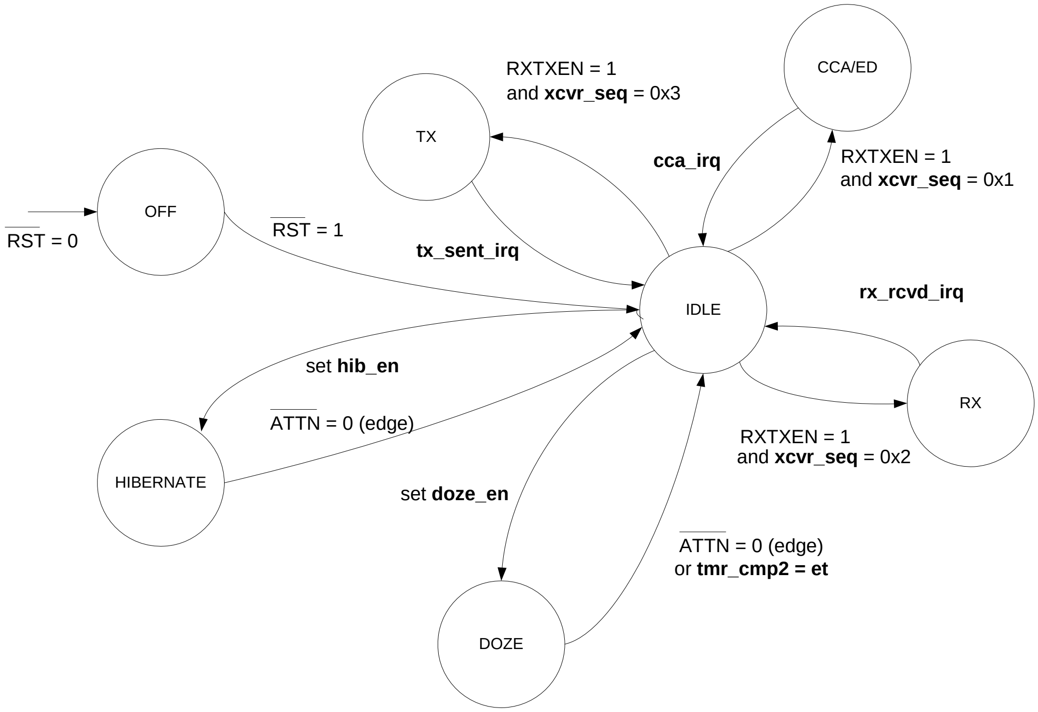


Figure 6-1. State Diagram for Packet Mode Without Timer Enabled States

Figure 6-2 shows state diagrams transceiver operations with timer-initiated sequences.

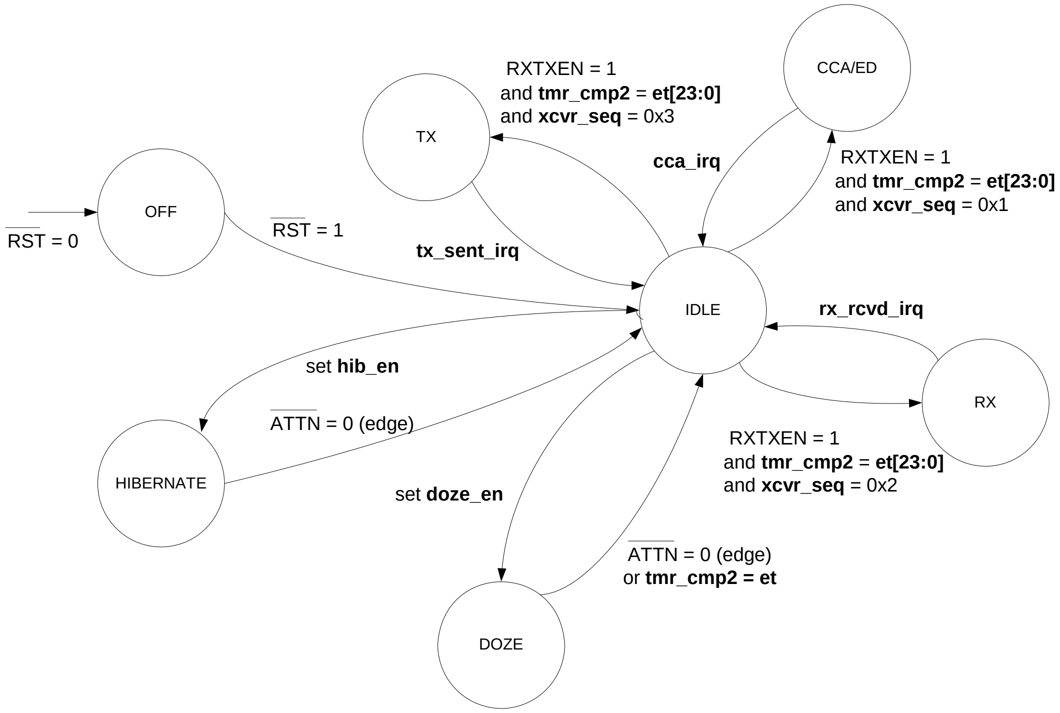


Figure 6-2. State Diagram for Packet Mode With Tmr_Cmp2 Enabled States (tmr_trig_en =1)

6.2 Low Power Modes

The MC13201 supports several low-power modes where the transceiver circuitry is not active. Each mode has a different advantage, these modes are described in the following sections.

6.2.1 Off Mode

The Off or Reset condition has the absolutely lowest power, and is controlled by the $\overline{\text{RST}}$ input. As long as $\overline{\text{RST}}$ is asserted low the MC13201 remains in the Off mode. All functions are disabled and no RAM data is retained. Current draw is attributed to leakage only.

To exit Off mode, $\overline{\text{RST}}$ is negated high. The MC13201 then moves to Idle mode within 25 milliseconds.

6.2.2 Hibernate Mode

Although the Off or Reset condition has the lowest possible power, the Hibernate mode has the next lowest power. All hardware blocks are deactivated (including the SPI interface) and no timers are running. Internal voltage regulation is dropped to less than 1 Vdc. Hibernate mode has the advantage of retention of all RAM data (which does not occur in the Off mode) and of the SPI configuration prior to entering Hibernate mode.

Hibernate mode is entered from Idle by programming hib_en, Control_B Register 07, Bit 1, to “1”. Hibernate is then entered 128 CLKO cycles after hib_en is set. The only way to exit from Hibernate mode is to assert $\overline{\text{ATTN}}$ which will cause the MC13201 to go to Idle mode or to assert $\overline{\text{RST}}$.

On entering Hibernate Mode, 128 clock cycles are available at CLKO before the clock is disabled. These 128 CLKO cycles allow a host that uses CLKO as a source clock to attain a low power state prior to losing clock. After the 128 CLKO cycles, the transceiver transitions to the low power state.

6.2.3 Doze Mode

Doze mode has variations of normal Doze mode and a subset called Acoma state.

6.2.3.1 Normal Doze Mode

Doze mode is an additional low power state specifically designed to work in concert with the Event Timer. Most internal hardware blocks are de-activated (including the SPI interface) and internal regulation is reduced, but the reference oscillator and Event Timer are active. Internal RAM data and SPI configuration are retained similar to Hibernate mode.

In Doze mode, CLKO can optionally be made available by setting clko_doze_en, Control_B Register 07, Bit 9, with the disadvantage of increased power consumption. The CLKO frequency must be set for 1 MHz or lower. If clko_doze_en = 0, then CLKO is disabled 128 clock cycles after entering Doze mode. After the 128 CLKO cycles, the transceiver transitions to the low power state.

Doze mode is entered from Idle by programming doze_en, Control_B Register 07, Bit 0, to “1”. Doze mode is then entered 128 CLKO cycles after doze_en is set.

The intended primary way to exit Doze mode is through a “wake-up” timer and return to Idle at a pre-determined time. This will occur when the Event Timer equals the value in tmr_cmr2[23:0], Tmr_Cmp2, Registers 1D and 1E. When the match occurs, The MC13201 exits Doze, sets status bit doze_irq, IRQ_Status Register 24, Bit 9, and returns to Idle. An interrupt request will be generated if the doze_mask IRQ_Mask Register 05, Bit 4, has been set.

If CLKO was enabled before Doze mode and disabled during Doze mode, the CLKO will automatically re-start after exiting Doze with the exception of two frequencies. The two lowest frequencies of 16.393+ kHz and 32.786+ kHz will not restart directly when exiting Doze mode. To restart CLKO for these frequencies, the clko_en, Control_C Register 09, Bit 2, must be cleared and set again.

Doze mode can be exited at any time similar to Hibernate by asserting $\overline{\text{ATTN}}$ or $\overline{\text{RST}}$. If Doze is exited by asserting $\overline{\text{ATTN}}$ and the Event Timer was activated and waiting on a timeout to waken, the timer should be disabled or the timeout will still happen and generate a status and possible interrupt.

6.2.3.2 Acoma Doze Mode

A subset of Doze mode without timer wake-up is the Acoma state that has the advantage of lowest power with data retention while allowing CLKO to run. This mode disables the Event Timer and prescaler, but allows the clock to run and have CLKO available. Timers are not available so only $\overline{\text{ATTN}}$ will return the device to Idle or a $\overline{\text{RST}}$ can be used to exit. Acoma mode is entered by setting acoma_en, IRQ_Mask Register 05, Bit 8 = 1.

6.3 Active Modes

There are four active modes for the MC13201 which include, Idle, Transmit (TX), Receive (RX) and Clear Channel Assessment (CCA)/Energy Detect (ED).

6.3.1 Idle Mode

Idle Mode is the default mode after leaving one of the low-power modes and is the basic active state from which all other activity is initiated. In Idle Mode, the receiver hardware and transmitter hardware are shut down waiting for a command. The command can instruct the MC13201 to transition to Receive mode, Transmit mode, CCA mode, or to one of the low-power modes. The transition to RX Mode or TX Mode or CCA / ED mode (in its variations) is called by writing to the xcvr_seq[1:0] field, Control_A Register 06, Bits 1 - 0.

Once CCA, Receive, or Transmit is entered, the MC13201 will transition back to the Idle mode upon completion of the selected operation. At the end of the operation, the xcvr_seq[1:0] field will not be cleared to an Idle value although the transceiver returns to the Idle condition. In this case, a read from the xcvr_seq[1:0] field will return the code of the last programmed operation.

In Idle Mode, the crystal oscillator is active, CLKO is available (if enabled), and the SPI is active.

6.3.2 Controlling Transition to Other Active Modes from Idle

Reviewing the state diagrams in Figure 6-1 and Figure 6-2 shows that the input signal RXTXEN must be asserted to allow transition from Idle to other active states. The recommended procedure is that RXTXEN is taken low while setting-up the desired function (writing required registers) and then after SPI transactions, the MCU raises RXTXEN to a high state enabling the transition. For timed functions (using either tmr_cmp2), the same procedure holds with the exception that the transition will be delayed until the timer function completes.

6.3.3 Packet Mode Data Transfer TX and RX Operation

The Idle mode is the condition from which RX and TX modes are initiated. Writing to the xcvr_seq[1:0] field arms the transition to the desired mode. However, the RXTXEN signal must also be high for the transition to occur and if the Event Timer is enabled, the transition will be synchronized to the timer compare event. Once Receive or Transmit is entered, the MC13201 will transition back to the Idle mode upon completion of the selected operation.

Table 6-2 shows the transceiver sequence field modes.

Table 6-2. Transceiver Sequence Field (xcvr_seq[1:0])

Mode	Value	Description
Idle	00	Idle mode - default state after exiting low-power modes
CCA / Energy Detect	01	CCA / Energy detect - special case of receive used to monitor channel energy
Packet Receive	10	Packet Receive
Packet Transmit	11	Packet Transmit

The selected mode is controlled by:

1. xcvr_seq[1:0] field - Shown in Table 6-2.
2. RXTXEN signal - The transition to any other active mode from Idle will not occur unless RXTXEN is asserted high.
3. tmr_trig_en, Control_A Register 06, Bit 7 - When tmr_trig_en is set to “1”, the transition to the selected active mode will be based on a tmr_cmp2[23:0] compare function as described in the Event Timer section. When tmr_trig_en is cleared to “0”, the transition to the selected active mode is based only on programming of xcvr_seq[1:0]. For both cases, RXTXEN must be high and overrides.

6.3.3.1 Packet Receive Mode

Receive mode is the state where the transceiver is waiting for an incoming data frame. The packet receive mode allows the MC13201 to receive the whole packet without intervention from the microcontroller. The entire packet payload is stored in RX Packet RAM and the microcontroller fetches the data after determining the length and validity of the RX packet.

The MC13201 waits for preamble followed by a Start of Frame Delimiter. From there, the Frame Length Indicator is used to determine length of the frame and calculate CRC. The receive function provides the following frame information/data:

1. The frame payload data - accessed through rx_pkt_ram[15:0] RX_Pkt_RAM Register 01.
2. CRC valid status - reported by crc_valid, IRQ_Status Register 24, Bit 0.
3. Payload data length - reported by rx_pkt_latch[6:0], RX_Pkt_Latch Register 2D, Bits 6 - 0.
4. Link quality indicator (LQI) - this is a measure of the received energy that occurs during the received frame. Once a preamble is detected, the received energy is measured over a 64 µs period and stored in cca_final[7:0], RX_Pkt_Latch Register 2D, Bits 15 - 8.

NOTE

After a frame is received, the application must determine the validity of the packet. Due to noise, it is possible for an invalid packet to be reported with either of the following conditions:

a.) A valid CRC and a frame length of 0,1, or 2

b.) Invalid CRC and invalid frame length

The application software needs to verify that:

a.) The CRC is valid

b.) The frame length is valid with a value of 3 or greater

The following is a typical sequence for receive operation (not using a timer-based start):

NOTE

This sequence shows use of the TXTXEN signal to control a sequence. The RXTXEN signal can be tied high and left high. The sequence will then start based on writing of the field xcvr_seq[1:0].

1. The RX frequency must be programmed.
2. If not already low, the MCU sets RXTXEN low.
3. Control bit tmr_trig_en = 0.
4. rx_rcvd_mask, Control_A Register 06, Bit 8 is programmed to “1” to enable an interrupt request when the RX packet has been received.
5. Transceiver sequence is programmed to xcvr_seq[1:0] = 0x2 for receive.
6. RXTXEN must be asserted and held high.
7. When a packet is successfully received, the following are reported:
    a) rx_pkt_latch[6:0], RX_Pkt_Latch Register 2D, Bits 6 - 0 - reports the length of the packet payload including 2 bytes of CRC data.
    b) crc_valid, IRQ_Status Register 24, Bit 0 - reports the results of the CRC check, where a “1” indicates valid CRC.
    c) cca_final[7:0], RX_Pkt_Latch Register 2D, Bits 15 - 8 - reports Link Quality Indicator.

   d) rx_rcvd_irq, IRQ_Status Register 24, Bit 7- reports the completion of packet reception, where a "1" indicate complete status. Also, an interrupt is generated due to the valid status.
8. In response of the interrupt request from the MC13201, the microcontroller does the following:
   a) Determines the validity of the frame by reading and checking rx_rcvd_irq and crc_valid. Determines a valid length for the frame by reading rx_pkt_latch[6:0].
   b) Reads the payload data from RX Packet RAM using a recursive read from rx_pkt_ram[15:0] RX_Pkt_RAM Register 01.

6.3.3.2 Aborting a Packet Receive Sequence

It may be required to abort a packet receive sequence. The RX sequence can be aborted by either negating RXTXEN to low or by writing xcvr_seq[1:0] to 0x0. If either of these conditions happen, the transceiver returns to Idle mode and no additional status bit is set.

6.3.3.3 Packet Transmit Mode

Packet transmit mode allows the MC13201 to send the whole packet without intervention from the microcontroller. The entire packet payload is pre-loaded in TX Packet RAM, the MC13201 sends the frame, and then the transmit complete status is given to the MCU.

NOTE

This sequence shows use of the TXTXEN signal to control a sequence. The RXTXEN signal can be tied high and left high. The sequence will then start based on writing of the field xcvr_seq[1:0].

The following is a typical sequence for packet transmit operation (not using a timer-based start):

1. The TX frequency must be programmed.
2. If not already low, the MCU sets RXTXEN low.
3. Control bit tmr_trig_en = 0.
4. tx_sent_mask, Control_A Register 06, Bit 9 is programmed to "1" to enable an interrupt request when the TX packet has been sent.
5. The MCU loads the value of the number of data bytes plus two (for FCS) into tx_pkt_length[6:0] TX_Pkt_Ctl Register 03, Bits 6 - 0.
6. The MCU then pre-loads the number of actual data bytes into tx_pkt_ram[15:0] TX_Pkt_RAM register 02 with a recursive SPI write. An odd number of data bytes requires stuffing a dummy byte due to the 16-bit SPI data format.
7. Transceiver sequence is programmed to xcvr_seq[1:0] = 0x3 for transmit.
8. RXTXEN must be asserted and held high.
9. When the packet is successfully transmitted, tx_sent_irq reports the completion of packet transmission, where a "1" indicates a complete status. Also, an interrupt is generated due to the valid status.
10. In response of the interrupt request from the MC13201, the microcontroller reads the status to clear the interrupt and check successful transmission.

6.3.4 Clear Channel Assessment (CCA) Modes (including Link Quality Indication)

A special case of receive function called Clear Channel Assessment (CCA) modes is available to measure received energy from the selected channel. The CCA function exists as two algorithms:

1. Clear channel assessment - measuring channel energy and comparing to a preset threshold.
2. Energy detect (ED) - measuring channel energy and giving an indication of measured strength.

The energy detect algorithm is also used for Link Quality Indication (LQI) during a normal RX operation. The LQI is reported as part of the RX operation.

The CCA modes are associated with the following register fields:

1. cca_type[1:0], Control_A Register 06, Bits 5 - 4, determines channel energy assessment algorithm where value 0x1 selects CCA and value 0x2 selects energy detect.
2. cca_vt[7:0], CCA_Thresh Register 04, Bits 15 - 8, sets the threshold level for the CCA function.
3. The average power of the signal is displayed in field cca_final[7:0], RX_Pkt_Latch Register 2D, Bits 15 - 8. This field is used for CCA, ED, and as LQI during an RX operation.
4. power_comp[7:0], CCA_Thresh Register 04, Bits 7-0, provides an offset that is added to the measured value of the average energy from a CCA/ED function or LQI value from an RX function.
5. Status bit cca, IRQ_Status Register 24, Bit 1, is used only for the CCA algorithm and is set to “1” when a busy channel is detected.
6. Status bit cca_irq_status, IRQ_Status Register 24, Bit 5, is set to “1” when the power measurement is complete for CCA or ED. If cca_mask, Control_A Register 06, Bit 10, is set an interrupt request will be also generated when the cca_irq_status is set.
7. For CCA Mode, it is preferred that tx_strm, rx_strm and use_strm_mode control bits should be cleared to zero.

6.3.4.1 Clear Channel Assessment Function

The CCA function measures the average energy of the channel and compares it to a preset threshold. In CCA mode, the receiver first warms-up from Idle in 144 µs. The average value of the signal power, as measured over the next 128 µs (8 symbol periods), is calculated and stored in cca_final[7:0].

To determine the decimal equivalent of the value stored in cca_final[7:0], one must convert the hex value to its decimal value, divide by two, and change the sign; where this calculated value is equivalent to the received signal strength in dBm:

Signal strength in dBm = - (dec (cca_final[7:0] / 2))

The value stored in cca_final[7:0] is also affected by an offset stored in power_comp[7:0], CCA_Thresh Register 04, Bits 7-0. The default value of power_comp[7:0] = 0x8D and is added to the measured value during the CCA/ED/LQI function to give the stored value in cca_final[7:0].

The compensation number added to the internal measured value is power_comp[7:0] / 2 and the resulting addition is shown in Figure 6-3.

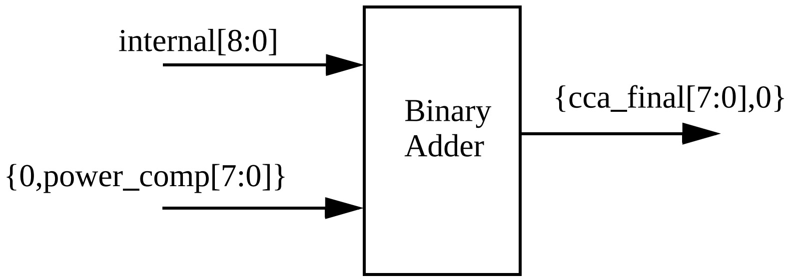


Figure 6-3. Compensation factor added to internal CCA value to produced corrected final value

The resulting formula for dBm means that the power_comp[7:0] value must be incremented or decremented by 4 to cause a 1 dBm change, which equates to a 1/4 dBm resolution for the power_comp correction.

The power_comp[7:0] default value is 0x8D and the value must be incremented to set a lower final CCA value. As an example, if one were putting in -30 dBm signal and the cca_final[7:0] was reporting -26 dBm, then the correction value in power_comp[7:0] should be increased by (4 * delta) or (4 * 4) in this case. The new compensated value of power_comp[7:0] = 0x8D + 0x10 = 0x9D.

NOTE

> The default value for power_comp[7:0] is 0x8D. To center the reported cca_final[7:0] value over temperature, it is suggested that a value of 0x9B be written to power_comp[7:0], which equates to a 3.5dBm offset from default.

Since the AGC is set to a fixed gain during the CCA procedure, input signals above -65 dBm will not be reflected correctly due to saturation.

NOTE

> For the graph below, the required 802.15.4 Standard accuracy and range limits are shown. A 3.5 dBm offset has been programmed into the CCA reporting level to center the level over temperature in the graph.

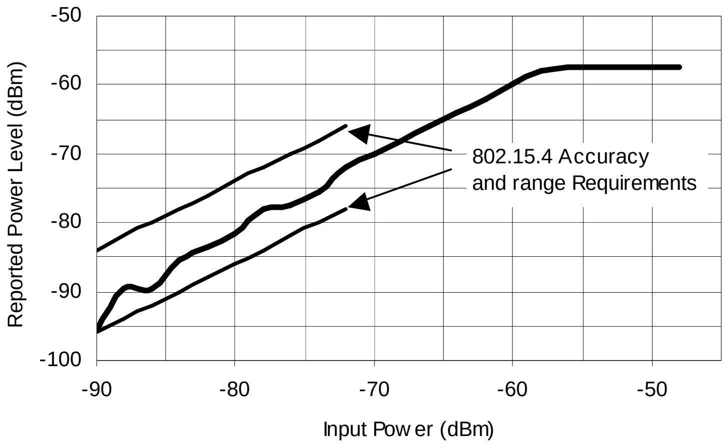


Figure 6-4. CCA Reported Power Level vs. Input Power

The value contained in cca_final[7:0], is compared to the preset threshold of cca_vt[7:0], CCA_Thresh Register 04, Bits 15 - 8. If cca_final[7:0] is equal to or less than the threshold, then cca is set to 1, indicating a busy channel. If cca_final[7:0] is greater than the threshold, cca remains at 0. Once the CCA operation is complete, cca_irq is asserted.

The value of cca_vt[7:0] is calculated:

Threshold value = hex (| (Threshold Power in dBm) * 2 |)

A suggested threshold is -82 dBm or 0xA4 = cca_vt[7:0].

The following is a typical sequence for CCA operation (not using a timer-based start):

1. The RX frequency must be programmed.
2. If not already low, the MCU sets RXTXEN low.
3. The CCA threshold must be programmed (cca_vt[7:0] = 0xA4 as an example).
4. cca_mask, Control_A Register 06, Bit 10 is programmed to “1” to enable an interrupt request when the CCA operation is complete.
5. cca_type[1:0], Control_A Register 06, Bits 5 - 4, is programmed to “01” to select the CCA algorithm.
6. Transceiver sequence is programmed to xcvr_seq[1:0] = 0x1 for CCA mode.
7. RXTXEN must be asserted and held high.
8. When the measurement is complete, the following are reported:
    a) cca_final[7:0], RX_Pkt_Latch Register 2D, Bits 15 - 8 - reports the average power level
    b) cca, IRQ_Status Register 24, Bit 1, is set to “1” when a busy channel is detected.
    c) cca_irq, IRQ_Status Register 24, Bit 5, is set to “1” to indicate complete status. Also, an interrupt is generated due to the valid status.
9. In response of the interrupt request from the MC13201, the microcontroller does the following:
    a) Determines the busy status of the channel by reading and checking cca_irq and cca.
    b) If required the power level can be determined by reading cca_final[7:0].

6.3.4.2 Energy Detect Function

With the energy detect algorithm, the exact same procedure results as the CCA operation without the threshold comparison. The receiver warms-up from Idle in 144 μs and the received power is measured over the next 128 μs (8 symbol periods). The average power is calculated and stored in cca_final[7:0].

NOTE

For the graph below, the required 802.15.4 Standard accuracy and range limits are shown. A 3.5 dBm offset has been programmed into the CCA reporting level to center the level over temperature in the graph.

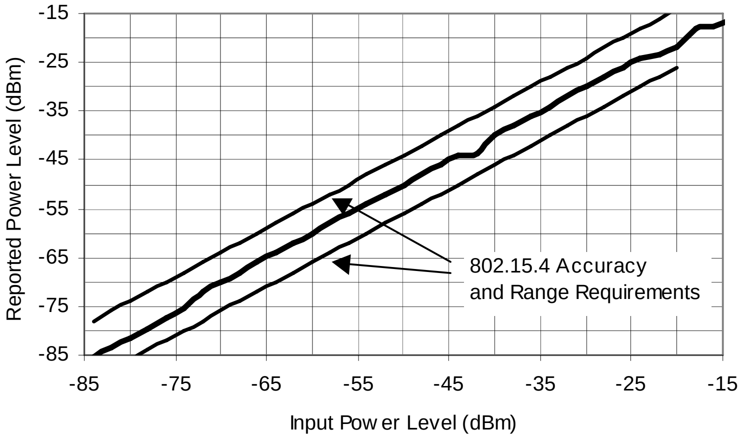


Figure 6-5. ED and LQI Reported Power vs. Input Power

Status bit cca is unaffected by energy detect. Once the energy detect operation is complete, cca_irq is asserted.

The following is a typical sequence for ED operation (not using a timer-based start):

1. The RX frequency must be programmed.
2. If not already low, the MCU sets RXTXEN low.
3. cca_mask, Control_A Register 06, Bit 10 is programmed to “1” to enable an interrupt request when the CCA operation is complete.
4. cca_type[1:0], Control_A Register 06, Bits 5 - 4, is programmed to “10” to select the ED algorithm.
5. Transceiver sequence is programmed to xcvr_seq[1:0] = 0x1 for CCA mode.
6. RXTXEN must be asserted and held high.
7. When the measurement is complete, the following are reported:
   a) cca_final[7:0], RX_Pkt_Latch Register 2D, Bits 15 - 8 - reports the average power level
   b) cca_irq, IRQ_Status Register 24, Bit 5, is set to “1” to indicate complete status. Also, an interrupt is generated due to the valid status.
8. In response of the interrupt request from the MC13201, the microcontroller can determine the power level by reading cca_final[7:0].

6.3.4.3 Link Quality Indication

Link Quality Indication is a measure of the signal quality during an actual receive operation. Its value is stored in field cca_final[7:0], RX_Pkt_Latch Register 2D, Bits 15 - 8. The format for the LQI is the same as CCA:

Signal strength in dBm = - (dec (cca_final[7:0] / 2))

Typical values of LQI returned from an RX operation are from about -95dBm to about -18dBm giving a cca_final[7:0] range of decimal values 190 (0xBE) to 36 (0x24). These are typical and may vary.

6.4 Frequency of Operation

The MC13201 is designed to operate in the 2.4 GHz band, covering 16 channels and using 5 MHz of spacing between each channel. The MC13201 uses two local oscillators (LO). The first LO synthesizer is the main LO for the receiver and the carrier generator for the transmitter. This block is comprised of a Fractional-N (Frac-N) PLL frequency synthesizer.

The fractional and integer components of the Frac-N must be programmed properly to perform a transceiver operation on a particular channel. The channels and the respective, required bit values of the integer setting are shown in the LO1_Int_Div Register 0F, Bits 7-0 (lo1_idiv[7:0]) and the fractional setting are shown in LO1_Num Register 10 (lo1_num[15:0]). See Table 4-17.

6.4.1 Transmit Power Adjustment

The PA output power can be controlled via programming of the PA_Lvl Register 12[7:0], whose fields include pa_lvl_course[1:0], pa_lvl_fine[1:0], pa_dr_coarse[1:0], and pa_dr_fine[1:0]. The programmable range of differential power is typically -27 dBm to +4 dBm. Table 6-3 shows the device power output versus SPI register settings for PA_Lvl Register 12[7:0].

NOTE

Register12[7:0] value of 0xBC is the default setting and yields a nominal power out of 0 dBm. Also, common practice is to allow Register 12[3:0] to stay at its default value of 0xC and only adjust the pa_lvl_coarse and pa_lvl_fine fields as required; this allows a range of about -16 dBm to +2.6 dBm.

Table 6-3. MC13201 Power Output vs. SPI Settings (Register 12)

PA Power Adjust Reg 12[7:0] (Hex)	Typical Differential Power at Output Contact (dBm)	Comments
00	-28.7	
04	-22.0	
08	-18.5	
0C	-16.2	Reg 12[3:0] default
1C	-15.9	Reg 12[3:0] default
2C	-15.3	Reg 12[3:0] default
3C	-14.8	Reg 12[3:0] default
4C	-8.5	Reg 12[3:0] default
5C	-7.6	Reg 12[3:0] default
6C	-7.2	Reg 12[3:0] default
7C	-7.0	Reg 12[3:0] default
8C	-1.7	Reg 12[3:0] default

Table 6-3. MC13201 Power Output vs. SPI Settings (Register 12) (continued)

PA Power Adjust Reg 12[7:0] (Hex)	Typical Differential Power at Output Contact (dBm)	Comments
9C	-1.6	Reg 12[3:0] default
AC	-0.77	Reg 12[3:0] default
BC (default)	-0.66	Reg 12[7:0] default
CC	0.62	Reg 12[3:0] default
DC	1.19	Reg 12[3:0] default
EC	1.23	Reg 12[3:0] default
FC	1.42	Reg 12[3:0] default
FD	2.2	
FE	2.9	
FF	3.4	

6.5 2.4GHz PLL Out-of-Lock Interrupt

Successful wireless data transmission and reception is predicated on the proper channel frequency being maintained internally by the MC13201. Sophisticated control circuitry and design techniques assure that the internal 2.4GHz local oscillator stays on the selected channel frequency. In the unusual event that the PLL loses lock, the host is notified via the 'Out-of-Lock Interrupt'. If lock indication circuitry indicates an out-of-lock condition, status bit pll_lock_irq, IRQ_Status Register 24, Bit 15, is set and any RX or TX operation in progress is automatically terminated. The MC13201 returns immediately to the IDLE state to await interrupt service routine handling. Also, the $\overline{\text{IRQ}}$ is asserted provided the mask bit pll_lock_mask, IRQ_Mask Register 05, Bit 9, is set.

NOTE

It is recommended that software enable the pll_lock_mask during CCA, RX, and TX operations. The pll_lock_irq status bit will get set by an out-of-lock condition and MUST be cleared by an IRQ_Status Register read before another CCA, RX, or TX operation can be enabled. As stated above an out-of-lock condition will abort the present operation and if the pll_lock_irq status is not cleared, any subsequent CCA, RX, or TX operation requested will be immediately aborted.

Examples of where this could be troublesome is in Packet Mode RX or a CCA operation. If the RX or CCA is aborted due to an out-of-lock condition, no rx_done_irq status or cca_irq status will be set and a corresponding IRQ signal will not be asserted, and as a result, no interrupt will be generated unless the pll_lock_irq is enabled to generate an interrupt.

Chapter 7
Timer Information

7.1 Event Timer Block

The MC13201 contains an internal Event Timer block that manages system timing. A simplified block diagram is shown in Figure 7-1.

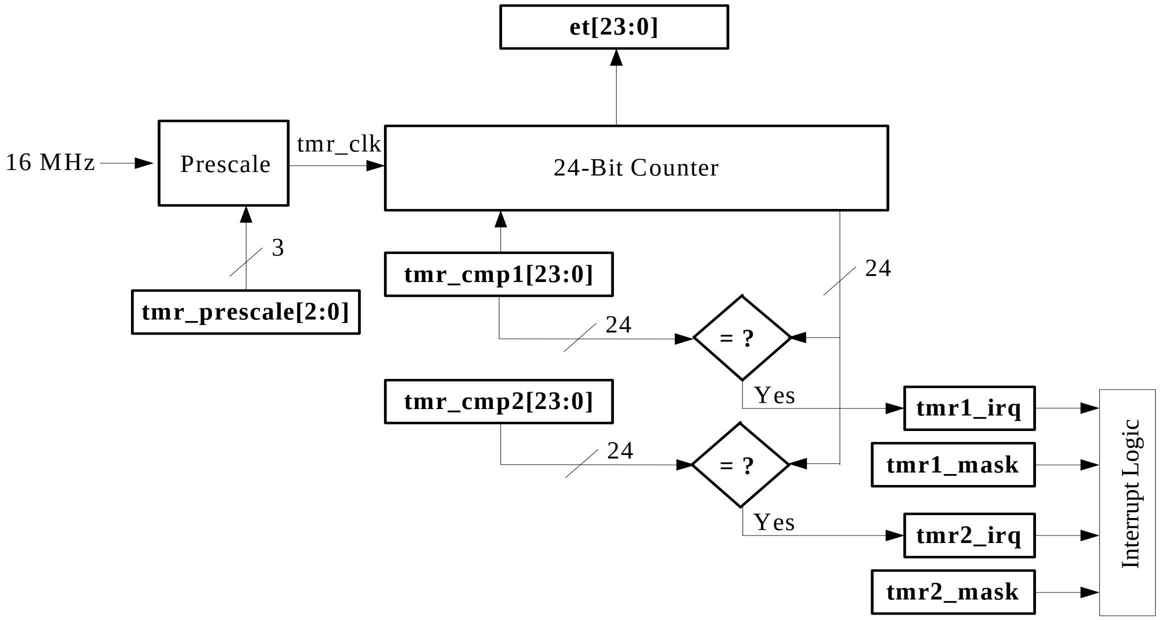


Figure 7-1. Event Timer Block Diagram

The MC13201 contains an internal Event Timer block that manages system timing. A simplified block diagram is shown in Figure 7-1. The Event Timer consists of a prescaler and a 24-bit counter which increment whenever the crystal clock is operating. Interrupts to the MCU may be generated when the “current time” of the counter (et[23:0]) matches several pre-determined values set in registers via SPI write operations. The current time is accessible at any time via a SPI read operation, as well as, programmable via a SPI write operation. The Event Timer provides the following functions:

- Timer to generate current system time
- Interrupt generation at pre-determined system times
- Exit from Doze mode at pre-determined system time
- Latches “timestamp” value during packet reception
- Initiates timer-triggered sequences

7.2 Event Timer Time Base

The Event Timer’s base clock (tmr_clk) is derived from a programmable prescaler which is clocked by the 16 MHz crystal source. The prescaler provides counter input frequencies from 2 MHz down to 15.625 kHz, which sets the granularity and resolution of the current time. The prescaler, and thus the Event Timer only increment when the crystal oscillator is active. The field tmr_prescale[2:0] Control_C Register 9, Bits 2-0 establishes the tmr_clk frequency as shown in Table 7-1.

Table 7-1. Event Timer Prescaler Settings

Register 9, Bits 2-0 tmr_prescale [2:0]	Event Timer Time Base	Maximum Event Timer Duration
000	2 MHz	8.389 seconds
001	1 MHz	16.777 seconds
010	500 kHz	33.554 seconds
011 (default)	250 kHz	67.109 seconds
100	125 kHz	134.218 seconds
101	62.5 kHz	268.436 seconds
110	31.25 kHz	536.871 seconds
111	15.625 kHz	1073.742 seconds

The 24-bit counter automatically rolls over upon reaching its maximum value, and the corresponding maximum possible Event Timer durations are also provided in Table 7-1.

7.3 Setting Current Time

“Current Time” is defined as the value of the Event Timer internal counter. The current time is programmable, but does not have to be programmed. In the reset condition, the MC13201 current time is set to zero. Current time advances from zero at the tmr_clk clock rate and rolls over to zero after reaching its maximum value.

Programming “current time” is accomplished by using three SPI registers:

1. Tmr_Cmp1_A Register 1B, Bits 7-0, tmr_cmp1[23:16]
2. Tmr_Cmp1_B Register 1C, Bits 15-0, tmr_cmp1[15:0]
3. Control_B Register 07, Bit 15, tmr_load

When field tmr_load is programmed to high, the value of “current time” is set to the value in tmr_cmp1[23:0]. Thus, tmr_cmp1[23:0] is first programmed to the desired current time value, then tmr_load is programmed to 1, which initiates the timer load. The change to the “current time” value occurs within two crystal clock cycles, after which normal incrementing resumes on the next rising tmr_clk edge. So, tmr_load is not required to be programmed to zero for the Event Timer to resume normal operation. However, loading the Event Timer is a positive edge-triggered event, so tmr_load must be programmed low prior to the next attempt to load the Event Timer.

7.4 Reading Current Time

The current value of the Event Timer can be read via the SPI using et[23:16], Current_Time_A Register 26, Bits 7-0, and et[15:0], Current_Time_B Register 27, Bits 15-0. The “current time” may be obtained using two single SPI reads, or one recursive 2-word SPI read (or as part of a longer recursive read operation as well). It is important to realize that the Event Timer may increment during these recursive SPI read operations, or between successive SPI reads if single SPI reads are used. During such an access, the MC13201 latches the “current time” to protect the host from obtaining an incorrect value. The “current time” least significant 16 bits (LSB) are latched when the most significant 8 bits (MSB) SPI location is read. The LSB is unlatched after the “current time” LSB location is read. This guarantees a stable value until the host completes a read of both words constituting the “current time” before it is allowed to update.

The preferred procedure to obtain the “current time” value from the MC13201 is to perform a 2-word recursive read of the “current time” starting at the MSB address.

7.5 Latching the Timestamp

The MC13201 has the ability create a Timestamp or to latch a copy of the “current time” while continuing to increment its internal counter. This timestamp value latched within the Event Timer corresponds to the beginning of a receive packet where the actual payload data begins after the FLI has been received. The timestamp[23:0] (Register 2E, Bits 7-0 and Register 2F, bits 15-0) value is read from the MC13201 by the host. When timestamp[23:0] is latched, its value corresponds to the “current time” value coincident with the reception of rx_pkt_latch[6:0], RX_Pkt_Latch Register 2D, Bits 6-0. The timestamp remains latched until another packet is received, at which point the timestamp[23:0] is updated and re-latched.

7.6 Event Timer Comparators

The MC13201 incorporates two full 24-bit programmable fields that compare to the Event Timer’s “current time”. The intent of these compares is to enable the host to schedule events relative to the “current time”. When a match between the “current time” and any one of the two timer compare values occurs, a corresponding flag is sent to internal interrupt logic. This causes the appropriate bit in the IRQ_Status Register 24 to be set, and depending on the interrupt mask control bit, generate an interrupt event on the IRQ pin.

7.6.1 Timer Compare Fields

There are two 24-bit timer compare fields:

1. tmr_cmp1[23:0], Tmr_Cmp1_A Register 1B, Bits 7-0, and Tmr_Cmp1_B Register 1C, Bits 15-0.
2. tmr_cmp2[23:0], Tmr_Cmp2_A Register 1D, Bits 7-0, and Tmr_Cmp2_B Register 1E, Bits 15-0.

7.7 Timer Disable Bits

Each timer comparator has a disable bit that enables or disables the compare function. The disable bit is written to a “1” to disable the corresponding comparator and the default condition is the timer enabled (reset to “0”):

1. tmr_cmp1_dis, Tmr_Cmp1_A Register 1B, Bit 15.
2. tmr_cmp2_dis, Tmr_Cmp2_A Register 1D, Bit 15.

If a timer comparator is disabled using its associated bit, the corresponding status bit (tmrx_irq) will also be cleared if set and will negate an associated interrupt.

7.7.1 Timer Status Flags

When enabled, all four fields can be continuously compared to the current value of the Event Timer counter. When a match occurs, the following corresponding internal status flags assert:

1. tmr1_irq, IRQ_Status Register 24, Bit 8.
2. tmr2_irq, IRQ_Status Register 24, Bit 2.

The status bit remains set until a read access of the IRQ_Status register occurs or if the timer comparator disable bit is set to disable an active comparator.

7.7.2 Timer Interrupt Masks

When a comparator match occurs and the internal status flag asserts, the following interrupt masks can enable an interrupt on the IRQ pin:

1. tmr1_mask, IRQ_Mask Register 05, Bit 0.
2. tmr2_mask, IRQ_Mask Register 05, Bit 1.

If the interrupt mask is set to “1” (enabled), the timer compare status will cause an interrupt and the interrupt signal will stay active until the status bit is cleared via an IRQ_Status read.

7.7.3 Setting Compare Values

Since the primary timer compare fields are 24-bit values, they are each shared between two sequential SPI register addresses. The timer compare value can be changed using two single SPI writes, or one recursive 2-word SPI write (or as part of a longer recursive write operation as well).

NOTE

It is important to realize that not all bits of the timer compare value are updated simultaneously within the SPI. To prevent the Event Timer from generating a false match to a partially updated timer compare value, the compare hardware is inhibited temporarily. The inhibit feature initiates when the address of the MSB location of the timer compare field is decoded on a SPI write, and ends when a write to the LSB field is completed. Thus, once a SPI write to the MSB location starts, the comparator is disabled until a SPI write to the LSB location is completed. The preferred procedure for software to change a timer compare value within the MC13201 is to perform a 2-word recursive write of the timer compare field starting at the MSB address.

7.8 Intended Event Timer Usage

It is intended that the system utilize the “current time” value and the timer compare functions of the Event Timer to schedule system events, including:

- Generating time-based interrupts
- Exiting Doze mode
- Triggering transceiver operations

NOTE

The timer_compare functions exit reset with the timer function enabled but with the interrupts masked off. Users should disable all timers and clear the IRQ_Status Register via a read as part of system initialization after reset.

7.8.1 Generating Time-Based Interrupts

Generating time-based interrupts is accomplished by setting timer compare values relative to the “current time”, allowing the Event Timer counter to increment until a timer compare match is generated, and using this match to generate an interrupt to the host. The general procedure is as follows:

1. Disable the timer compare. This clears the status flag if already set.
2. Enable the timer compare interrupt mask.
3. Read the “current time” value from et[23:0].
4. Add an offset to this value to equal desired “future time”.
5. Program the appropriate timer_compare value to “future time”.
6. Program the appropriate tmr_cmpx_dis bit to enable the compare.
7. Allow a timer compare match to set the status register bit and generate an interrupt. The appropriate internal status register bit is always set upon a timer_compare match. An external interrupt is generated when the corresponding SPI interrupt mask bit, Register 5, Bits 1 or 0, is set.

8. Program the appropriate tmr_cmpx_dis bit to disable the compare function. If this is not done, the compare function will continue to run and generate another interrupt every time the counter rolls over and again matches the comparator.

7.8.2 Using tmr_cmp2[23:0] to Exit Doze Mode

The Event Timer provides a timer-based mechanism to bring the MC13201 out of Doze mode. The MC13201 is put into Doze mode when doze_en, Control_B Register 07, Bit 0, is programmed high. While in Doze mode, a match between “current time” and field tmr_cmp2[23:0] causes the MC13201 to exit Doze mode and return to Idle Mode.

The general procedure is as follows:

1. Read the “current time” value from et[23:0].
2. Add an offset to this value to equal desired “future time” to exit Doze mode.
3. Program field tmr_cmp2[23:0] to value “future time”.
4. Program doze_mask, Register 05, Bit 4, to 1.
5. Program doze_en, Register 7, Bit 0, to 1. The MC13201 then enters Doze mode.(Note that the control bit tmr_cmp2_dis has no effect on this mode).
6. When “current time” equals tmr_cmp2[23:0], the MC13201 exits Doze mode, and doze_irq, Register 24, Bit 9, gets set. An external interrupt is also generated because doze_mask is set.

NOTE

> The MC13201 can always be taken out of Doze Mode by asserting $\overline{\text{ATTN}}$ or $\overline{\text{RST}}$. Also, if acoma_en IRQ_Mask Register 05, Bit 8 is set before entering Doze mode, the Event Timer logic is disabled for additional power savings and only $\overline{\text{ATTN}}$ or $\overline{\text{RST}}$ will cause exit of Doze mode.

7.8.3 Timer-Triggered Transceiver Events

An Event Timer can be used to initiate the MC13201 transceiver operations such as transmit and receive. The desired operation can be scheduled to commence at a future time greater than the “current time” by using the MC13201 timer-triggered operation capability. Timer-triggered operations are invoked by using tmr_cmp2 [23:0]. A time greater than the “current time” is programmed into the appropriate compare field and tmr_trig_en, Control_A Register 6, Bit 7 is programmed high. When the “current time” advances to match the value set in the compare field, the selected operation sequence will commence automatically without intervention from the host. This allows the host to arm the MC13201 to execute a desired operation at a future time, and go off to perform other necessary system functions.

The general procedure is as follows:

1. Desired frequency must be programmed.
2. If not already low, the MCU sets RXTXEN low.
3. Read the “current time” value from et[23:0].
4. Add an offset to this value to equal desired “future time” to initiate selected operation.
5. Program field tmr_cmp2[23:0] to value “future time”.

6. Program tmr_cmp2_dis to 0 to enable the compare function.
7. If desired, program tmr2_mask, IRQ_Mask Register 05, Bit 1 high to enable an interrupt when the timer compare function completes and starts the transceiver.
8. For a TX operation only, load tx_pkt_length[6:0] and payload data into tx_pkt_RAM[15:0].
9. Program tmr_trig_en, Control_A Register 6, Bit 7 high to enable a timer-based operation.
10. Program the MC13201 for the desired transceiver operation via xcvr_seq[1:0].
11. Assert the RXTXEN pin and hold high.
12. When “current time” equals tmr_cmp2[23:0], the MC13201 initiates the selected transceiver operation. When tmr2_irq, IRQ_Status Register 24, Bit 2 is set to 1, an external interrupt is generated if the interrupt mask bit (tmr2_mask) was set high.

NOTE

tmr_trig_en is level sensitive. It is not necessary to program it to 0 prior to the next timer triggered operation.

13. Once started, the transceiver operation commences in a normal manner.

Chapter 8
Interrupt Description

8.1 Interrupts

Interrupts provide a way for the MC13201 to inform the host microcontroller (MCU) of onboard events without requiring the MCU to constantly query MC13201 status.

For a given event, the interrupt flow is as follows.

- The source interrupt mask is enabled.
- The source function is enabled.
- The source event occurs causing the source status flag to be set and the $\overline{\text{IRQ}}$ pin to be asserted low.
- The $\overline{\text{IRQ}}$ pin stays asserted until the $\overline{\text{IRQ}}$_Status Register is read to determine the source of the interrupt. Reading the IRQ_Status Register clears the status bits and releases the $\overline{\text{IRQ}}$ signal to be negated high.

When multiple source events have occurred, the MCU must use the IRQ_Status register contents to determine all the present events that caused an interrupt, prioritize them, and respond to all of the them. This is done through the interrupt service routine of the MCU.

8.1.1 Interrupt Sources

Table 8-1 lists the interrupt status bits, mask bits, and source description.

Table 8-1. MC13201 Interrupt Sources

Item	Status Bit	Mask Bit	Source Description	Interrupt Clear Mechanism[1]
1	pll_lock_irq	pll_lock_mask	PLL out of lock.	Read IRQ_Status Reg
2	ram_addr_err	ram_addr_mask	RAM address error - a recursive access to Packet RAM has exceeded the maximum RAM address.	Read IRQ_Status Reg
3	arb_busy_err	arb_busy_mask	Arbitration busy error - a SPI access to Packet RAM was attempted during packet reception or transmission.	Read IRQ_Status Reg
4	attn_irq	attn_mask	The $\overline{\text{ATTN}}$ signal has been asserted or the MC13201 has reached a Power-up complete condition after a reset.	Read IRQ_Status Reg
5	doze_irq	doze_mask	While in Doze mode, a tmr_cmp2 match has occurred and the MC13201 will return to Idle mode.	Read IRQ_Status Reg

Table 8-1. MC13201 Interrupt Sources (continued)

Item	Status Bit	Mask Bit	Source Description	Interrupt Clear Mechanism[1]
6	rx_rcvd_irq	rx_rcvd_mask	The current RX packet has been received, data in Packet RAM is ready to be read, and the transceiver has returned to Idle Mode.	Read IRQ_Status Reg
7	tx_sent_irq	tx_sent_mask	The current TX packet in Packet RAM has been completely transmitted, and the transceiver has returned to Idle Mode.	Read IRQ_Status Reg
8	cca_irq	cca_mask	The Clear Channel Assessment operation has been completed.	Read IRQ_Status Reg
9	tmr1_irq	tmr1_mask	Tmr_cmp1 match has been made.	Read IRQ_Status Reg or set tmr_cmp1_dis bit
10	tmr2_irq	tmr2_mask	Tmr_cmp2 match has been made. (Not functional when Tmr_cmp2 is used to exit Doze Mode).	Read IRQ_Status Reg or set tmr_cmp2_dis bit

[1] Although some status bits can be cleared by other means, reading IRQ_Status register will always clear all status bits.

8.1.2 Output Pin $\overline{\mathrm{IRQ}}$

The $\overline{\mathrm{IRQ}}$ signal is an open drain output that is asserted low when an interrupt request is pending. The signal is released to high by reading the IRQ_Status register via an SPI transaction. $\overline{\mathrm{IRQ}}$ is an open drain output that requires a passive pullup and it also can be programmed for drive strength.

8.1.2.1 Programming $\overline{\mathrm{IRQ}}$ Pullup

A passive pullup is required on $\overline{\mathrm{IRQ}}$ and may be done via two methods:

1. Use the onboard (nominal 40 Kohm) pullup resistor - Set irqb_pup_en bit, GPIO_Data_Out Register 0C, Bit 7, to activate. This is the default mode.
2. Use an external resistor (value should be greater than 4 Kohms).

8.1.2.2 Setting $\overline{\mathrm{IRQ}}$ Output Drive Strength

$\overline{\mathrm{IRQ}}$ output drive strength is programmed by writing to irqb_drv[1:0], GPIO_Data_Out Register 0C. There are 4 levels of drive strength with field value 00 for lowest and value 11 for greatest. The default value is 00.

NOTE

It is suggested the user leave $\overline{\mathrm{IRQ}}$ at greatest drive strength for best performance.

8.2 PLL_lock_irq Status Bit and Operation

As described in Section 4.23, “IRQ_Status - Register 24, pll_lock_irq status bit indicates the LO1 PLL has come out of lock during a TX, RX, or CCA (ED) transceiver operation. If the LO1 unlocks during the transceiver operation, the device returns to Idle mode, and the pll_lock_irq status bit gets set as expected. The application software must read the IRQ_Status Register 24 (clearing the pll_lock_irq status bit) before attempting any further transceiver active operations (TX, RX or CCA). If the status bit is not cleared, any subsequent active operation will abort immediately. This condition occurs because the LO1 unlock causes an operation abort and the status bit must be cleared or any follow-on operation will also abort.

The best practice is to enable the pll_lock_irq interrupt so that $\overline{\mathrm{IRQ}}$ will be asserted if an unlock occurs.

- If the pll_lock_irq interrupt is not enabled and an LO1 unlock occurs, no rx_rcvd_irq status will be set for an RX operation nor will a cca_irq status be set for a CCA operation because the operation was aborted. As a result, an interrupt cannot be generated, and any follow-on operation will be aborted
- If the pll_lock_irq interrupt is not enabled for a TX operation and an unlock occurs, the tx_sent_irq status will be set when the TX aborts, so an interrupt can be generated. However, any follow-on operation will still be aborted if the IRQ_Status Register is not read

8.3 Attn_irq Status Bit and Interrupt Operation

As described in Section 4.23, “IRQ_Status - Register 24, attn_irq status bit indicates:

- The transceiver has achieved Idle status (full power-up) after the release of the $\overline{\mathrm{RST}}$ signal. The default condition out of reset leaves the attn_irq interrupt request enabled, and upon the transceiver reaching Idle, the attn_irq status is set and the IRQ signal is asserted
- Signal $\overline{\mathrm{ATTN}}$ has been asserted (normally to release the transceiver from Hibernate or Doze mode) and the transceiver has exited the low power mode. The $\overline{\mathrm{IRQ}}$ signal will be asserted if the interrupt has not been masked

8.4 Interrupts from Exiting Low Power Modes

The MC13201 has three low power modes and interrupt generation differs somewhat for each mode.

8.4.1 Exiting Off Mode (Reset)

The transceiver is put in reset and stays in reset (Off Mode) through the assertion of $\overline{\mathrm{RST}}$. The initialization done at reset enables attn_mask which allows an interrupt request when attn_irq is set. One condition that sets attn_irq is when the transceiver exits reset after $\overline{\mathrm{RST}}$ is released high. As a result, an interrupt request will always be generated by attn_irq status when reset is exited.

8.4.2 Exiting Hibernate Mode

Hibernate is normally only exited through assertion of $\overline{\text{ATTN}}$ (obviously $\overline{\text{RST}}$ can still override). The attn_irq status will be set by the assertion of $\overline{\text{ATTN}}$. If an interrupt is desired to signify the event, the attn_mask bit must be set before entering Hibernate. The interrupt request will then be generated due to the attn_irq being set true upon exit from Hibernate.

8.4.3 Exiting Doze Mode(s)

Doze can be exited via assertion of $\overline{\text{ATTN}}$ or through use of tmr_cmp2 (again reset can override). Asserting $\overline{\text{ATTN}}$ will always cause Doze to be exited even if the timer option is enabled. If an interrupt is desired, set attn_mask before entering Doze which will cause the interrupt when the attn_irq status is set upon exiting Doze due to $\overline{\text{ATTN}}$.

Alternately, Doze has the option of using tmr_cmp2 to exit, except for Acoma Mode which cannot use the timer. When tmr_cmp2 match occurs the doze_irq status will be set. An interrupt request will also occur if doze_mask bit has been enabled.

Chapter 9
Miscellaneous Functions

9.1 Reset Function

The MC13201 can be placed in one of two reset conditions either through hardware input $\overline{\text{RST}}$ or by writing to Reset Register 00.

9.1.1 Input Pin $\overline{\text{RST}}$

Asserting input pin $\overline{\text{RST}}$ low places the transceiver in a complete reset condition (Off Mode and power down), and the device stays in this reset mode until $\overline{\text{RST}}$ is released high. After $\overline{\text{RST}}$ is released, the transceiver will transition to the Idle Mode within 25 milliseconds

9.1.2 Software Reset (Writing to Register 00)

Writing to Reset Register 00 causes a reset condition where the digital logic is reset, but the transceiver is not powered down. The device is forced to the Idle Mode and the SPI registers are all reset and forced to their default condition although all data in the Packet RAMs is retained. The reset is held as long as $\overline{\text{CE}}$ remains asserted and is released when $\overline{\text{CE}}$ is negated high.

9.1.3 Reset Indicator Bit (RST_Ind Register 25, Bit 7)

It is useful to determine if the transceiver has powered-up from a reset condition or from a low power state that was released via the $\overline{\text{ATTN}}$ signal. The reset indicator bit (reset_ind, RST_Ind Register 25, Bit 7) is cleared during a reset operation but not during a low power mode such as Doze or Hibernate. The reset_ind bit gets set by the first read of Register 25 after a reset operation and stays set until another reset operation.

When exiting reset, an interrupt is generated by attn_irq, IRQ_Status Register 24, Bit 10, (the default condition is with the interrupt mask enabled). This same interrupt can be enabled for exiting Hibernate or Doze via an $\overline{\text{ATTN}}$ assertion. As a result, the reset_ind bit can determine if the power-up condition is from the reset condition or a Doze or Hibernate condition.

After exiting reset and responding to the attn_irq interrupt, users should read Register 25 which in turn sets the reset_ind bit. Thereafter, if the transceiver is put into Doze or Hibernate and then later awakened by an $\overline{\text{ATTN}}$ assertion, the attn_irq interrupt is also used, but the reset_ind is set signifying that the chip was not reset and does not need re-initialized.

9.2 General Purpose Input/Output

The MC13201 has seven general purpose input/output (GPIO) pins (GPIO1 through GPIO7). Features include:

- CMOS logic levels with +/- 1 mA load current
- Programmable as inputs or outputs
- No programmable pullups are provided
- During reset outputs are disabled and exit reset as inputs

NOTE

> Unused GPIO pins must be dealt with in one of two ways to prevent floating inputs. They first may be tied to ground via a hardware connection. If the user desires to leave the GPIO pin not hard-wired (for future use), the initialization of the transceiver should configure the unused GPIO as an output set to the low state to prevent excess current as well as a floating input.

- Not capable of generating an interrupt
- Once programmed as an output, a GPIO keeps its state if the transceiver transitions to Doze or Hibernate mode

9.2.1 Configuring GPIO Direction

The GPIO are configured using GPIO_Dir Register 0B. Each I/O has a gpiox_oen output enable bit and a gpiox_ien input enable bit. Exiting reset, the default condition for these enable bits is that the gpiox_ien bits are set to 1 which enables the pins as inputs and gpiox_oen are cleared.

NOTE

> If any bit is programmed to be an input and output simultaneously, the input condition overrides.

9.2.2 Setting GPIO Output Drive Strength

If any GPIO are programmed as outputs, their drive strength is programmable. GPIO1 through GPIO4 are programmed as a group for drive strength by writing to control field gpio1234_drv[1:0], GPIO_Dir Register 0B, and GPIO5 through GPIO7 are programmed as a group by writing to gpio567_drv[1:0], GPIO_Data_Out Register 0C. There are 4 levels of drive strength with field value 00 for lowest and value 11 for greatest.

9.2.3 Programming GPIO Output Value

GPIO_Data_Out Register 0C has a gpiox_o bit for each GPIO pin that establishes the corresponding output's state when that I/O is programmed as an output. Setting a gpiox_o to 1 sets the output high.

9.2.4 Reading GPIO Input State

GPIO_Data_In Register 28 has a gpiox_i bit for each GPIO pin. When a GPIO is programmed as an input, its state can be determined by reading the corresponding gpiox_i bit in the register.

9.2.5 GPIO1 and GPIO2 Status Indicators

To support easier and quicker status indication for the MCU, GPIO1 and GPIO2 can be programmed for special alternative functionality. If the gpio_alt_en bit of Control_C Register 09 is set to 1 then:

1. GPIO1 becomes an “Out of Idle” indicator (active high) - GPIO1 will always reflect the status of the internal state machine. If the MC13201 is in a TX or RX or CCA/ED sequence, the GPIO1 will be high. Once the sequence ends, the GPIO1 returns to a low state and shows that the transceiver has returned to Idle. In Doze or Hibernate mode GPIO1 stays low.
2. GPIO2 becomes a “Valid CRC” or “Valid CCA Result” indicator (active high) -
    a) For a RX sequence, the GPIO2 will show the CRC is valid once the RX operation is complete and GPIO1 goes to low to indicate a return to Idle condition. The transition of GPIO1 from high to low latches the CRC result on GPIO2 and that status will not change until the next transceiver sequence. GPIO2 will not be valid if an error condition such as a PLL out-of-lock condition occurs
    b) For a CCA sequence, the GPIO2 will show if the CCA is valid once the CCA operation is complete and GPIO1 goes to low to indicate a return to Idle condition. The transition of GPIO1 from high to low latches the CCA result on GPIO2 and that status will not change until the next transceiver sequence. GPIO2 will not be valid if an error condition such as a PLL out-of-lock condition occurs

These two signals can be used by the MCU to monitor transceiver status without interrogating the onboard status registers.

NOTE

GPIO1 and GPIO2 should also be programmed as outputs for this function.

9.3 Crystal Oscillator

The crystal oscillator for the MC13201 uses the following external pins:

1. XTAL1 - reference oscillator input.
2. XTAL2 - reference oscillator output. Note that this pin should not be loaded to be used as a reference source or to measure frequency; instead use CLKO to measure or supply 16 MHz.

The external crystal circuit is shown in Figure 9-1.

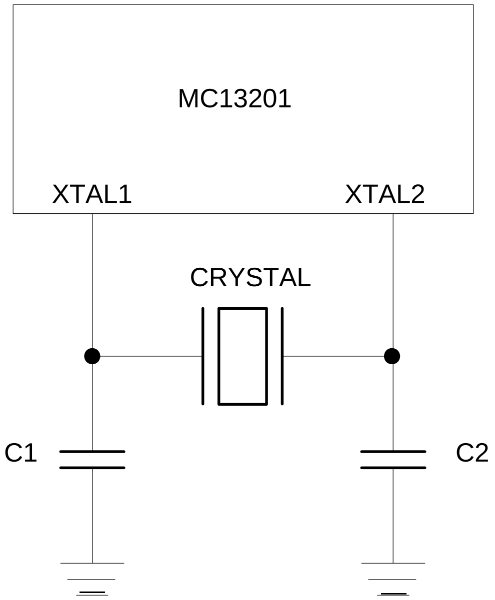


Figure 9-1. Crystal oscillator circuit

9.3.1 Crystal Requirements

The MC13201 requires that only a 16 MHz crystal with a <9 pF load capacitance can be used. The load capacitance limitation is required due to internal oscillator circuit and the ability to trim the oscillator as described in the next section. A tight frequency tolerance on the crystal may also be required due to the 802.15.4 Standard which demands that frequency tolerances be kept within +/- 40 ppm. This requirement is for the oscillator circuit, not just the crystal. This is covered in detail in the *MC13201 Data Sheet*, MC13201DS.

9.3.2 Crystal Trim Operation

The MC13201 uses the 16 MHz crystal oscillator with warp capability as the reference oscillator for the system. The warp capability is done by the MC13201 and is controlled by programming CLKO_Ctl Register 0A, Bits 15-8 (xtal_trim[7:0]). The trimming procedure varies the frequency by a few hertz per step, depending on the type of crystal. The high end of the frequency spectrum is set when xtal_trim[7:0] is set to zero. As xtal_trim[7:0] is increased, the frequency is decreased. Accuracy of this feature can be observed by varying xtal_trim[7:0] and using a spectrum analyzer or frequency counter to track the change in frequency of the crystal signal. The reference oscillator frequency can be measured at the CLKO contact by programming CLKO_Ctl Register 0A, Bits 2-0, to value 000. The crystal frequency should not be monitored at IC pins 26 or 27 (XTAL1 or XTAL2) because this will load the oscillator and alter the frequency.

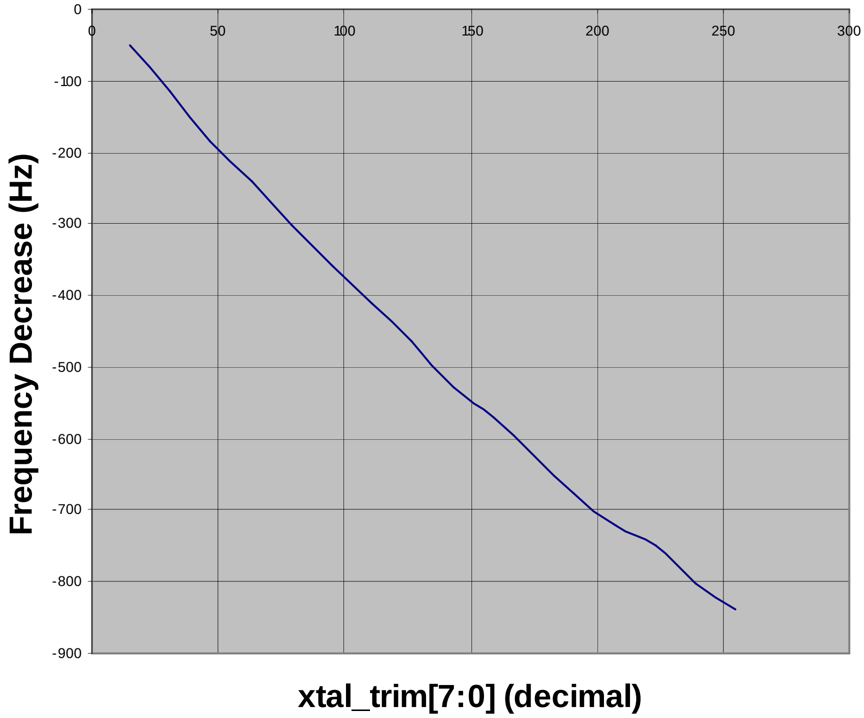


Figure 9-2. Crystal Frequency Variation vs. xtal_trim[7:0]

Figure 9-2 shows typical oscillator frequency decrease versus the value programmed in xtal_trim[7:0].

9.4 Output Clock Pin CLKO

The MC13201 can supply a clock output useful as a frequency source for a microcontroller, frequency test point, or reference for other uses. The clock output is available on signal CLKO and can be turned on or off as a power saving measure (default is CLKO active). CLKO is controlled by a number of control fields.

9.4.1 Enable CLKO (clko_en, Control_C Register 09, Bit 5)

Setting clko_en, Contro_C Register 9, Bit 5, to 1 enables the CLKO signal. The default condition out of reset is that the clock out is enabled at the default frequency of 32.768+ kHz set by field clko_rate[2:0].

9.4.2 Setting CLKO frequency (clko_rate[2:0], CLKO_Ctl Register 0A, Bits 2-0)

The 3-bit field clko_rate[2:0], CLKO_Ctl Register 0A, Bits 2-0, selects the output frequency based on the programmed value. Frequencies from 16 MHz to 16 kHz are available. Default frequency is 32.768+ kHz with a field value of clko_rate[2:0] = 110. Ταβλε 4–13 lists the CLKO frequencies versus clko_rate[2:0] program value.

9.4.3 Enable CLKO During Doze Mode (clko_doze_en, Control_B Register 07, Bit 9)

Bit clko_doze_en, Control_B register 07, Bit 9, is used to control CLKO during Doze mode. If clko_doze_en is set to 1 before entering Doze mode, CLKO will continue to toggle while the MC13201 is in Doze mode. The CLKO frequency must be set for 1 MHz or lower. Default out of reset is clko_doze_en = 0 as a power-saving measure.

If clko_doze_en = 0 and CLKO was enabled, CLKO will stop toggling 128 reference clock (16 MHz) cycles after the doze_en bit is programmed to 1. CLKO will automatically re-start after exiting Doze.

9.4.4 Setting CLKO Output Drive Strength (clko_drv[1:0], GPIO_Data_Out Register 0C, Bits 11-10)

The CLKO output drive strength can be programmed to 4 different levels by writing to clko_drv[1:0], GPIO_Data_Out Register 0C, Bits 11-10. The default value is the lowest drive value of 00. Note that for higher frequencies such as 16 MHz, the CLKO must be programmed for highest drive. Table 9-1 shows output drive strength for maximum frequency and maximum load capacitance.

Table 9-1. CLKO Drive Strength Versus clko_drv[1:0] Value

Drive Strength (clko_drv[1:0])	Max Freq (MHz)	Max C_{load} (pF)
00	1	20
01	8	20
10	16	20
11	16	$20<C_{load}$

9.5 Input Pin $\overline{\text{ATTN}}$

The attention or $\overline{\text{ATTN}}$ signal is used to exit either Doze mode or Hibernate mode.

NOTE

> Doze mode may also be exited via a tmr_cmp2 compare event. A transition event from high to low (assertion) on $\overline{\text{ATTN}}$ is required to exit either mode.

The $\overline{\text{ATTN}}$ assertion low event can also generate an interrupt. The interrupt status bit is attn_irq, IRQ_Status Register 24, Bit 10, and the interrupt mask bit is attn_mask, IRQ_Mask Register 05, Bit 15.