



# Si4320 Universal ISM Band FSK Receiver

## DESCRIPTION

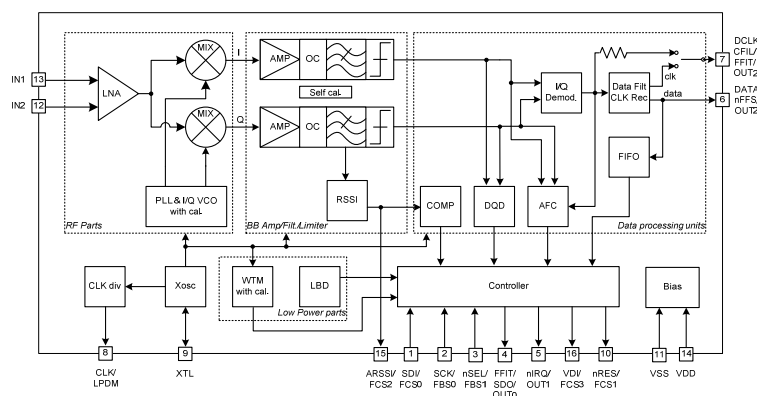
Silicon Labs' Si4320 is a single chip, low power, multi-channel FSK receiver designed for use in applications requiring FCC or ETSI conformance for unlicensed use in the 315, 433, 868, and 915 MHz bands. Used in conjunction with Si4220/21, Silicon Labs' FSK transmitters, the Si4320 is a flexible, low cost, and highly integrated solution that does not require production alignments. All required RF functions are integrated. Only an external crystal and bypass filtering are needed for operation.

The Si4320 has a completely integrated PLL for easy RF design, and its rapid settling time allows for fast frequency hopping, bypassing multipath fading, and interference to achieve robust wireless links. The PLL's high resolution allows the usage of multiple channels in any of the bands. The baseband bandwidth (BW) is programmable to accommodate various deviation, data rate, and crystal tolerance requirements. The receiver employs the Zero-IF approach with I/Q demodulation, therefore no external components (except crystal and decoupling) are needed in a typical application. The Si4320 is a complete analog RF and baseband receiver including a multi-band PLL synthesizer with an LNA, I/Q down converter mixers, baseband filters and amplifiers, and I/Q demodulator.

The chip dramatically reduces the load on the microcontroller with integrated digital data processing: data filtering, clock recovery, data pattern recognition and integrated FIFO. The automatic frequency control (AFC) feature allows using a low accuracy (low cost) crystal. To minimize the system cost, the chip can provide a clock signal for the microcontroller, avoiding the need for two crystals.

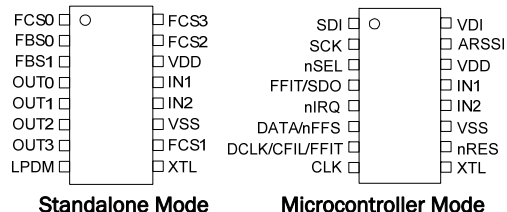
For simple applications, the receiver supports a standalone operation mode. This allows complete data receiver operation and control of four digital outputs based on the incoming data pattern without a microcontroller. In this mode, 12 or more predefined frequency channels can be used in any of the four bands. For low power applications, the device supports low duty-cycle operation based on the internal wake-up timer.

## FUNCTIONAL BLOCK DIAGRAM



## Si4320

### PIN ASSIGNMENT



**This document refers to Si4320-IC Rev J1.**

See [www.silabs.com/integration](http://www.silabs.com/integration) for any applicable errata. See back page for ordering information.

## FEATURES

- Fully integrated (low BOM, easy design-in)
- No alignment required in production
- Fast settling, programmable, high-resolution PLL
- Fast frequency hopping capability
- High bit rate (up to 115.2 kbps in digital mode and 256 kbps in analog mode)
- Direct differential antenna input
- Programmable baseband bandwidth (67 to 400 kHz)
- Analog and digital RSSI outputs
- Automatic frequency control (AFC)
- Data quality detection (DQD)
- Internal data filtering and clock recovery
- RX pattern recognition
- SPI compatible serial control interface
- Clock and reset signals for microcontroller
- 16 bit RX data FIFO
- Standalone operation mode without microcontroller
- Low power duty-cycle mode (less than 0.5 mA average supply current)
- Standard 10 MHz crystal reference with in circuit calibration
- Alternative OOK support
- Wake-up timer
- Low battery detector
- 2.2 to 5.4 V supply voltage
- Low power consumption (~9 mA in low bands)
- Low standby current (0.3  $\mu$ A)
- Compact 16-pin TSSOP package

## TYPICAL APPLICATIONS

- Remote control
- Home security and alarm
- Wireless keyboard/mouse and other PC peripherals
- Toy control
- Remote keyless entry
- Tire pressure monitoring
- Telemetry
- Personal/patient data logging
- Remote automatic meter reading

# DETAILED DESCRIPTION

## General

The Si4320 FSK receiver is the counterpart of the Si4220 FSK transmitter. It covers the unlicensed frequency bands at 315, 433, 868, and 915 MHz. The device facilitates compliance with FCC and ETSI requirements.

The receiver employs the Zero-IF approach with I/Q demodulation, allowing the use of a minimal number of external components in a typical application. The Si4320 consists of a fully integrated multi-band PLL synthesizer, an LNA with switchable gain, I/Q down converter mixers, baseband filters and amplifiers, and an I/Q demodulator followed by a data filter.

## PLL

The programmable PLL synthesizer determines the operating frequency, while preserving accuracy based on the on-chip crystal-controlled reference oscillator. The PLL's high resolution allows for the use of multiple channels in any of the bands.

The RF VCO in the PLL performs automatic calibration, which requires only a few microseconds. Calibration always occurs when the synthesizer begins. If temperature or supply voltage changes significantly or operational band has changed, VCO recalibration is recommended. Recalibration can be initiated at any time by switching the synthesizer off and back on again.

## LNA

The LNA has 250 Ohm input impedance, which works well with the recommended antennas. (See Application Notes available from [www.silabs.com/integration](http://www.silabs.com/integration).)

If the RF input of the chip is connected to 50 Ohm devices, an external matching circuit is required to provide the correct matching and to minimize the noise figure of the receiver.

The LNA gain (and linearity) can be selected (0, -6, -14, -20 dB relative to the highest gain) according to RF signal strength. This is useful in an environment with strong interferers.

## Baseband Filters

The receiver bandwidth is selectable by programming the bandwidth (BW) of the baseband filters. This allows setting up the receiver according to the characteristics of the signal to be received.

An appropriate bandwidth can be selected to accommodate various FSK deviation, data rate, and crystal tolerance requirements. The filter structure is a 7-th order Butterworth low-pass with 40 dB suppression at 2\*BW frequency. Offset cancellation is accomplished by using a high-pass filter with a cut-off frequency below 7 kHz. See Measurement Results section for measured receiver selectivity curves.

## Data Filtering and Clock Recovery

The output data filtering can be completed by an external capacitor or by using digital filtering according to the final application.

**Analog operation:** The filter is an RC type low-pass filter and a Schmitt-trigger (St). The resistor (10k) and the St is integrated on the chip. An (external) capacitor can be chosen according to the actual bit-rate. In this mode the receiver can handle up to 256 kbps data rate.

**Digital operation:** The data filter is a digital realization of an analog RC filter followed by a comparator with hysteresis. In this mode there is a clock recovery circuit (CR), which can provide synchronized clock to the data. With this clock the received data can fill the RX Data FIFO. The CR has three operation modes: fast, slow, and automatic. In slow mode, its noise immunity is very high, but it has slower settling time and requires more accurate data timing than in fast mode. In automatic mode the CR automatically changes between fast and slow modes. The CR starts in fast mode, then automatically switches to slow mode after locking.

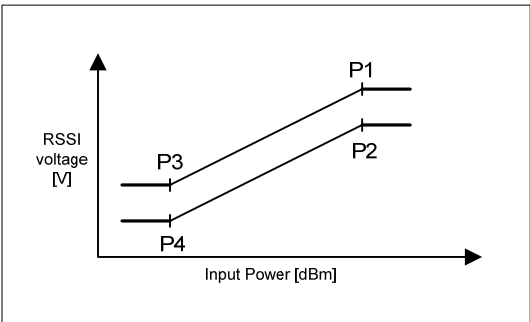
(Only the data filter and the clock recovery use the bit-rate clock. Therefore, in analog mode, there is no need for setting the correct bit-rate.)

## Data Validity Blocks

### RSSI

A digital RSSI output is provided to monitor the input signal level. It goes high if the received signal strength exceeds a given preprogrammed level. An analog RSSI signal is also available. The RSSI settling time depends on the filter capacitor used.

Voltage on ARSSI pin vs. Input RF power



|    |          |         |
|----|----------|---------|
| P1 | -65 dBm  | 1300 mV |
| P2 | -65 dBm  | 1000 mV |
| P3 | -100 dBm | 600 mV  |
| P4 | -100 dBm | 300 mV  |

## DQD

The Data Quality Detector monitors the I/Q output of the baseband amplifier chain by counting the consecutive correct 0->1, 1->0 transitions. The DQD output indicates the quality of the signal to be demodulated. Using this method it is possible to "forecast" the probability of BER degradation. The programmable DQD parameter defines the threshold for signaling the good/bad data quality by the digital one-bit DQD output. In cases when the deviation is close to the bitrate, there should be four transitions during a single one bit period in the I/Q signals. As the bitrate decreases in comparison to the deviation, more and more transitions will happen during a bitperiod.

## AFC

By using an integrated Automatic Frequency Control (AFC) feature, the receiver can synchronize its local oscillator to the received signal, allowing the use of:

- inexpensive, low accuracy crystals
- narrower receiver bandwidth (i.e. increased sensitivity)
- higher data rate

## Crystal Oscillator

The chip has a single-pin crystal oscillator circuit, which provides a 10 MHz reference signal for the PLL. To reduce external parts and simplify design, the crystal load capacitor is internal and programmable. Guidelines for selecting the appropriate crystal can be found later in this datasheet. The receiver can supply the clock signal for the microcontroller, so accurate timing is possible without the need for a second crystal.

When the microcontroller turns the crystal oscillator off by clearing the appropriate bit using the Configuration Setting Command, the chip provides a fixed number (128) of further clock pulses ("clock tail") for the microcontroller to let it go to idle or sleep mode.

## Low Battery Voltage Detector

The low battery detector circuit monitors the supply voltage and generates an interrupt if it falls below a programmable threshold level. The detector circuit has 50 mV hysteresis.

## Wake-Up Timer

The wake-up timer has very low current consumption (1.5  $\mu$ A typical) and can be programmed from 1 ms to several days with an accuracy of  $\pm 10\%$ .

It calibrates itself to the crystal oscillator at every startup. When the crystal oscillator is switched off, the calibration circuit switches it back on only long enough for a quick calibration (a few milliseconds) to facilitate accurate wake-up timing.

## Event Handling

In order to minimize current consumption, the receiver supports the sleep mode. Active mode can be initiated by several wake-up events (wake-up timer timeout, low supply voltage detection, on-chip FIFO filled up or receiving a request through the serial interface).

If any wake-up event occurs, the wake-up logic generates an interrupt signal, which can be used to wake up the microcontroller, effectively reducing the period the microcontroller has to be active. The cause of the interrupt can be read out from the receiver by the microcontroller through the SDO pin.

## Interface and Controller

An SPI compatible serial interface lets the user select the frequency band, center frequency of the synthesizer, and the bandwidth of the baseband signal path. Division ratio for the microcontroller clock, wake-up timer period, and low supply voltage detector threshold are also programmable. Any of these auxiliary functions can be disabled when not needed. All parameters are set to default after power-on; the programmed values are retained during sleep mode. The interface supports the read-out of a status register, providing detailed information about the status of the receiver and the received data. It is also possible to store the received data bits into the 16bit RX FIFO register and read them out in a buffered mode. FIFO mode can be enabled through the SPI compatible interface by setting the fe bit to 1 in the Output and FIFO Mode Command.

## Standalone Operation Mode

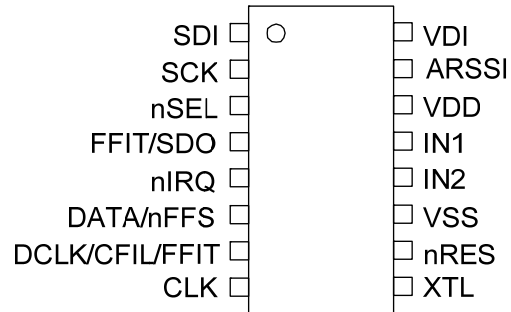
The chip also provides a standalone mode, which allows the use of the receiver without a microcontroller. This mode can be selected by connecting the CLK/LPDM pin to either VDD or VSS. After power on, the chip will check this pin. If it is connected to any supply voltage, then the chip will go to standalone mode. Otherwise, it will go to microcontroller mode and the pin will become an output and provide a clock signal for the microcontroller. To prevent the Si4320 from accidentally entering a standalone mode, the stray capacitance should be kept below 50 pF on pin 8.

In this mode operating parameters can be selected from a limited set by "programming" the receiver over its pins. The chip is addressable and four digital output pins can be controlled by the received data. Selecting the Low Power Duty-Cycle Mode (LPDM) the chip consumes less than 0.5 mA average current.

## PACKAGE PIN DEFINITIONS, MICROCONTROLLER MODE

Pin type key: D=digital, A=analog, S=supply, I=input, O=output, IO=input/output

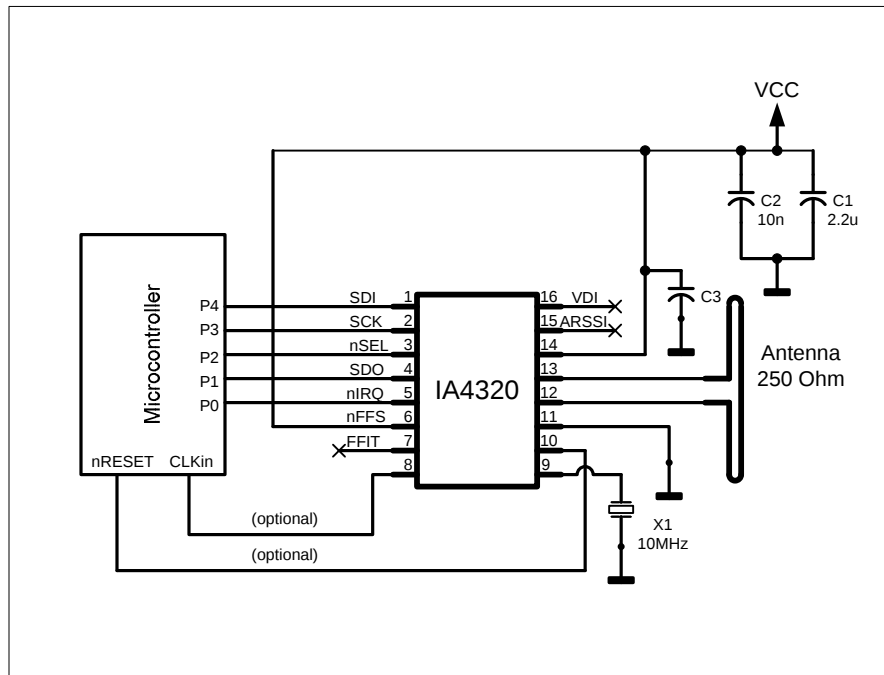
### Microcontroller Mode Pin Assignment



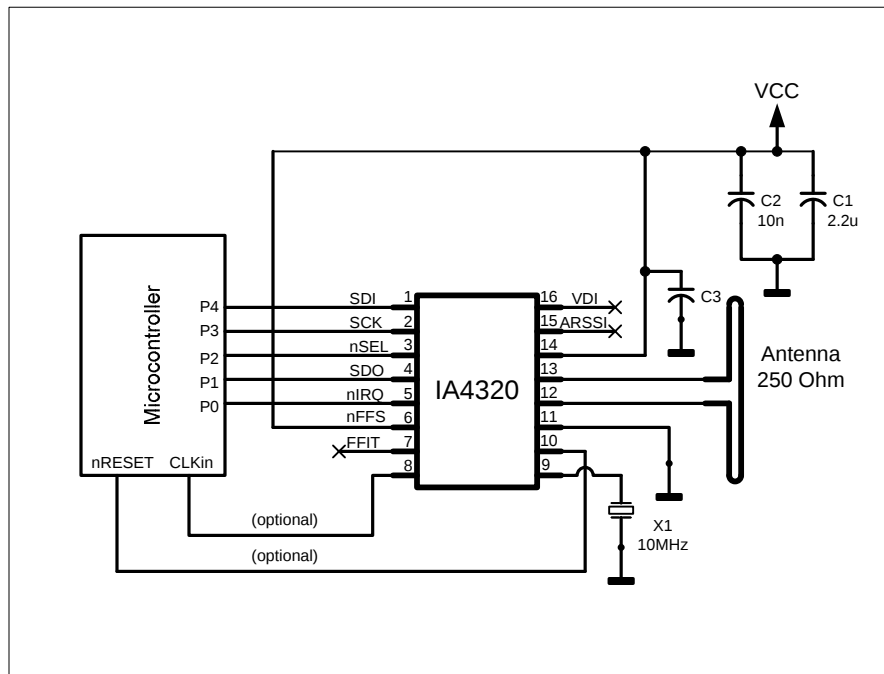
| Pin | Name     | Type | Function                                                                                              |
|-----|----------|------|-------------------------------------------------------------------------------------------------------|
| 1   | SDI      | DI   | Data input of serial control interface                                                                |
| 2   | SCK      | DI   | Clock input of serial control interface                                                               |
| 3   | nSEL     | DI   | Chip select input of three-wire control interface (active low)                                        |
| 4   | FFIT/SDO | DO   | FIFO IT (active low) or serial data out for Status Read Command. Tristate with bushold cell if nSEL=H |
| 5   | nIRQ     | DO   | Interrupt request output, (active low)                                                                |
| 6   | DATA     | DO   | Received data output (FIFO not used)                                                                  |
|     | nFFS     | DI   | FIFO select input (active low)                                                                        |
| 7   | DCLK     | DO   | Received data clock output (Digital filter used, FIFO not used)                                       |
|     | CFIL     | AIO  | External data filter capacitor connection (Analog filter used)                                        |
|     | FFIT     | DO   | FIFO IT (active high)<br>FIFO empty function can be achieved when FIFO IT level is set to one         |
| 8   | CLK      | DO   | Clock output for the microcontroller                                                                  |
| 9   | XTL/REF  | AIO  | Crystal connection (other terminal of crystal to VSS) / External reference input                      |
| 10  | nRES     | DO   | Reset output (active low)                                                                             |
| 11  | VSS      | S    | Negative supply voltage                                                                               |
| 12  | IN2      | AI   | RF differential signal input                                                                          |
| 13  | IN1      | AI   | RF differential signal input                                                                          |
| 14  | VDD      | S    | Positive supply voltage                                                                               |
| 15  | ARSSI    | AO   | Analog RSSI output                                                                                    |
| 16  | VDI      | DO   | Valid Data Indicator output                                                                           |

## Typical Application, Microcontroller Mode

### Minimal Microcontroller Mode



### Microcontroller Mode with FIFO usage

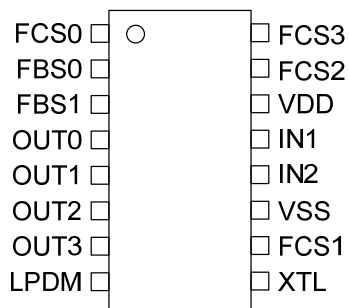


**Note:** For detailed information about the supply decoupling capacitors see page 7.

## PACKAGE PIN DEFINITIONS, STANDALONE MODE

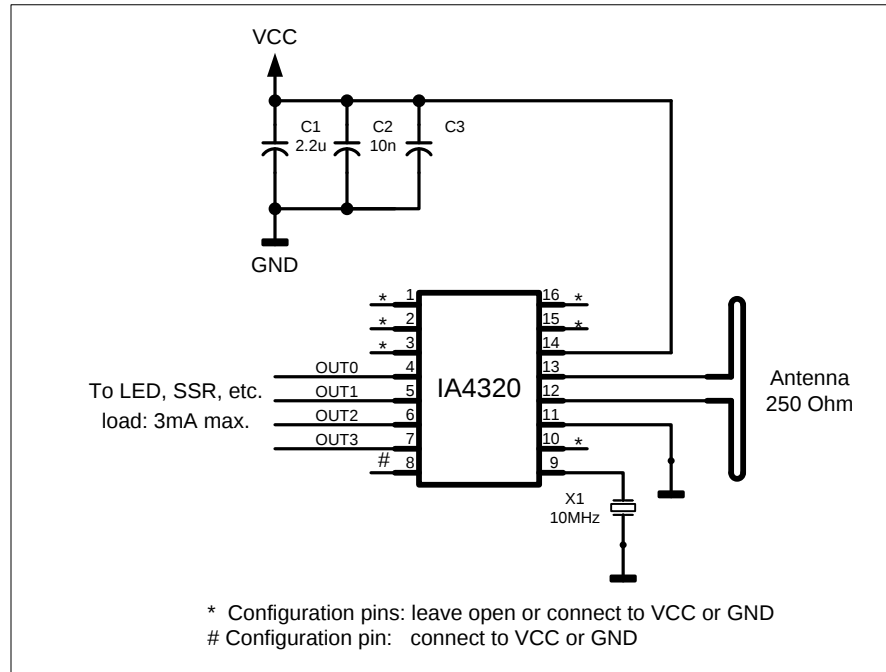
Pin type key: D=digital, A=analog, S=supply, I=input, O=output, IO=input/output

### Standalone Mode Pin Assignment



| Pin | Name | Type | Function                                                                          |
|-----|------|------|-----------------------------------------------------------------------------------|
| 1   | FCS0 | DI   | Frequency select input bit0                                                       |
| 2   | FBS0 | DI   | Band select input bit0                                                            |
| 3   | FBS1 | DI   | Band select input bit1                                                            |
| 4   | OUT0 | DO   | Control output bit0                                                               |
| 5   | OUT1 | DO   | Control output bit1                                                               |
| 6   | OUT2 | DO   | Control output bit2                                                               |
| 7   | OUT3 | DO   | Control output bit3                                                               |
| 8   | LPDM | DI   | Low power duty cycle mode select input                                            |
| 9   | XTL  | AIO  | Crystal connection (other terminal of crystal to VSS) or external reference input |
| 10  | FCS1 | DI   | Frequency select input bit1                                                       |
| 11  | VSS  | S    | Negative supply voltage                                                           |
| 12  | IN2  | AI   | RF differential signal input                                                      |
| 13  | IN1  | AI   | RF differential signal input                                                      |
| 14  | VDD  | S    | Positive supply voltage                                                           |
| 15  | FCS2 | DI   | Frequency select input bit2                                                       |
| 16  | FCS3 | DI   | Frequency select input bit3                                                       |

### Typical Application, Standalone Mode



### Recommended supply decoupling capacitor values

C2 and C3 should be 0603 size ceramic capacitors to achieve the best supply decoupling. The capacitor values are valid for both stand-alone and microcontroller mode.

| Band [MHz] | C1          | C2   | C3    |
|------------|-------------|------|-------|
| 315        | 2.2 $\mu$ F | 10nF | 390pF |
| 433        | 2.2 $\mu$ F | 10nF | 220pF |
| 868        | 2.2 $\mu$ F | 10nF | 47pF  |
| 915        | 2.2 $\mu$ F | 10nF | 33pF  |

## GENERAL DEVICE SPECIFICATIONS

All voltages are referenced to  $V_{ss}$ , the potential on the ground reference pin VSS.

### Absolute Maximum Ratings (non-operating)

| Symbol   | Parameter                                        | Min  | Max          | Units |
|----------|--------------------------------------------------|------|--------------|-------|
| $V_{dd}$ | Positive supply voltage                          | -0.5 | 6.0          | V     |
| $V_{in}$ | Voltage on any pin except open collector outputs | -0.5 | $V_{dd}+0.5$ | V     |
| $I_{in}$ | Input current into any pin except VDD and VSS    | -25  | 25           | mA    |
| ESD      | Electrostatic discharge with human body model    |      | 1000         | V     |
| $T_{st}$ | Storage temperature                              | -55  | 125          | °C    |
| $T_{ld}$ | Lead temperature (soldering, max 10 s)           |      | 260          | °C    |

### Recommended Operating Range

| Symbol   | Parameter                     | Min | Max | Units |
|----------|-------------------------------|-----|-----|-------|
| $V_{dd}$ | Positive supply voltage       | 2.2 | 5.4 | V     |
| $T_{op}$ | Ambient operating temperature | -40 | 85  | °C    |

## ELECTRICAL SPECIFICATION

(Test Conditions:  $T_{op} = 27\text{ °C}$ ;  $V_{dd} = V_{oc} = 3.3\text{ V}$ )

### DC Characteristics

| Symbol    | Parameter                                        | Conditions/Notes                              | Min                | Typ  | Max                | Units |
|-----------|--------------------------------------------------|-----------------------------------------------|--------------------|------|--------------------|-------|
| $I_{dd}$  | Supply current                                   | 315 / 433 MHz bands                           |                    | 9    | 11                 | mA    |
|           |                                                  | 868 MHz band                                  |                    | 10.5 | 12.5               |       |
|           |                                                  | 915 MHz band                                  |                    | 12   | 14                 |       |
| $I_{pd}$  | Standby current                                  | All blocks disabled                           |                    | 0.3  |                    | μA    |
| $I_{lb}$  | Low battery voltage detector current consumption |                                               |                    | 0.5  |                    | μA    |
| $I_{wt}$  | Wake-up timer current consumption (Note 1)       |                                               |                    | 1.5  |                    | μA    |
| $I_x$     | Idle current                                     | Crystal oscillator and base band parts are ON |                    | 3.0  | 3.5                | mA    |
| $V_{lb}$  | Low battery detect threshold                     | Programmable in 0.1 V steps                   | 2.25               |      | 5.35               | V     |
| $V_{lba}$ | Low battery detection accuracy                   |                                               |                    | +/-3 |                    | %     |
| $V_{il}$  | Digital input low level                          |                                               |                    |      | $0.3 \cdot V_{dd}$ | V     |
| $V_{ih}$  | Digital input high level                         |                                               | $0.7 \cdot V_{dd}$ |      |                    | V     |
| $I_{il}$  | Digital input current                            | $V_{il} = 0\text{ V}$                         | -1                 |      | 1                  | μA    |
| $I_{ih}$  | Digital input current                            | $V_{ih} = V_{dd}$ , $V_{dd} = 5.4\text{ V}$   | -1                 |      | 1                  | μA    |
| $V_{ol}$  | Digital output low level                         | $I_{ol} = 2\text{ mA}$                        |                    |      | 0.4                | V     |
| $V_{oh}$  | Digital output high level                        | $I_{oh} = -2\text{ mA}$                       | $V_{dd}-0.4$       |      |                    | V     |

**Note 1:** Using the internal wake-up timer and counter reduces the overall current consumption, which should permit approximately 6 months operation from a 1500mAh battery.

**AC Characteristics**

| Symbol               | Parameter                                            | Conditions/Notes                                                                                             | Min    | Typ                        | Max    | Units         |
|----------------------|------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|--------|----------------------------|--------|---------------|
| $f_{LO}$             | Receiver frequency                                   | 315 MHz band, 2.5 kHz resolution                                                                             | 310.24 |                            | 319.75 | MHz           |
|                      |                                                      | 433 MHz band, 2.5 kHz resolution                                                                             | 430.24 |                            | 439.75 |               |
|                      |                                                      | 868 MHz band, 5.0 kHz resolution                                                                             | 860.48 |                            | 879.51 |               |
|                      |                                                      | 915 MHz band, 7.5 kHz resolution                                                                             | 900.72 |                            | 929.27 |               |
| BW                   | Base-band bandwidth                                  | mode 0                                                                                                       | 60     | 67                         | 75     | kHz           |
|                      |                                                      | mode 1                                                                                                       | 120    | 134                        | 150    |               |
|                      |                                                      | mode 2                                                                                                       | 180    | 200                        | 225    |               |
|                      |                                                      | mode 3                                                                                                       | 240    | 270                        | 300    |               |
|                      |                                                      | mode 4                                                                                                       | 300    | 350                        | 375    |               |
|                      |                                                      | mode 5                                                                                                       | 360    | 400                        | 450    |               |
| BR                   | FSK bit rate                                         | With internal digital filters                                                                                |        |                            | 115.2  | kbps          |
| BRA                  | FSK bit rate                                         | With analog filter                                                                                           |        |                            | 256    | kbps          |
| $P_{min}$            | Receiver Sensitivity                                 | BER $10^{-3}$ , BW=67 kHz, BR=1.2 kbps (Note 1)                                                              |        | -109                       | -100   | dBm           |
| AFC <sub>range</sub> | AFC locking range                                    | $\delta f_{FSK}$ : FSK deviation in the received signal                                                      |        | $0.8 \cdot \delta f_{FSK}$ |        |               |
| IIP3 <sub>inh</sub>  | Input IP3                                            | In band interferers in high bands                                                                            |        | -21                        |        | dBm           |
| IIP3 <sub>outh</sub> | Input IP3                                            | Out of band interferers<br>$f - f_{LO} > 4\text{MHz}$                                                        |        | -18                        |        | dBm           |
| IIP3 <sub>inl</sub>  | IIP3 (LNA –6dB gain)                                 | In band interferers in low bands                                                                             |        | -15                        |        | dBm           |
| IIP3 <sub>outl</sub> | IIP3 (LNA –6dB gain)                                 | Out of band interferers<br>$f - f_{LO} > 4\text{MHz}$                                                        |        | -12                        |        | dBm           |
| $P_{max}$            | Maximum input power                                  | LNA: high gain                                                                                               | 0      |                            |        | dBm           |
| Rin                  | RF input impedance real part (differential) (Note 2) | LNA gain (0, -14dB)<br>LNA gain (-6, -20dB)                                                                  |        | 250<br>500                 |        | Ohm           |
| Cin                  | RF input capacitance                                 |                                                                                                              |        | 1                          |        | pF            |
| RS <sub>a</sub>      | RSSI accuracy                                        |                                                                                                              |        | +/-5                       |        | dB            |
| RS <sub>r</sub>      | RSSI range                                           |                                                                                                              |        | 46                         |        | dB            |
| C <sub>ARSSI</sub>   | Filter cap for ARSSI                                 |                                                                                                              | 1      |                            |        | nF            |
| RS <sub>step</sub>   | RSSI programmable level steps                        |                                                                                                              |        | 6                          |        | dB            |
| RS <sub>resp</sub>   | DRSSI response time                                  | Until the RSS output goes high after the input signal exceeds the preprogrammed limit $C_{ARSSI}=5\text{nF}$ |        | 500                        |        | $\mu\text{s}$ |

**Note 1:** See the BER diagrams in the measurement results section for detailed information.

**Note 2:** See matching circuit parameters and antenna design guide for information, and Application Notes available from [www.silabs.com/integration](http://www.silabs.com/integration).

**AC Characteristics (continued)**

| Symbol        | Parameter                                             | Conditions/Notes                                                                    | Min | Typ   | Max               | Units   |
|---------------|-------------------------------------------------------|-------------------------------------------------------------------------------------|-----|-------|-------------------|---------|
| $f_{ref}$     | PLL reference frequency                               | (Note 3)                                                                            | 8   | 10    | 12                | MHz     |
| $f_{res}$     | PLL frequency resolution                              | Depends on selected bands                                                           | 2.5 |       | 7.5               | kHz     |
| $t_{lock}$    | PLL lock time                                         | Frequency error < 1kHz after 10 MHz step                                            |     | 20    |                   | $\mu$ s |
| $t_{st, P}$   | PLL startup time                                      | With running crystal oscillator                                                     |     |       | 250               | $\mu$ s |
| $C_{xl}$      | Crystal load capacitance, see crystal selection guide | Programmable in 0.5 pF steps, tolerance +/- 10%                                     | 8.5 |       | 16                | pF      |
| $t_{POR}$     | Internal POR pulse width (Note 4)                     | After $V_{dd}$ has reached 90% of final value                                       |     | 50    | 150               | ms      |
| $t_{sx}$      | Crystal oscillator startup time                       | Crystal ESR < 100 Ohms (Note 5)                                                     |     | 1     | 5                 | ms      |
| $t_{PBT}$     | Wake-up timer accuracy                                | Crystal oscillator must be enabled to ensure proper calibration at startup (Note 5) |     | +/-10 |                   | %       |
| $t_{wake-up}$ | Programmable wake-up time                             |                                                                                     | 1   |       | $5 \cdot 10^{11}$ | ms      |
| $C_{in, D}$   | Digital input capacitance                             |                                                                                     |     |       | 2                 | pF      |
| $t_{r, f}$    | Digital output rise/fall time                         | 15 pF pure capacitive load                                                          |     |       | 10                | ns      |

**Note 3:** Using other than a 10 MHz crystal is not recommended because the crystal referred timing and frequency parameters will change accordingly.

**Note 4:** During this period, commands are not accepted by the chip. For detailed information see the *Reset modes* section.

**Note 5:** The crystal oscillator start-up time strongly depends on the capacitance seen by the oscillator. Using low capacitance and low ESR crystal is recommended. When designing the PCB layout keep the trace connecting to the crystal short to minimize stray capacitance.

## CONTROL INTERFACE

Commands to the receiver are sent serially. Data bits on pin SDI are shifted into the device upon the rising edge of the clock on pin SCK whenever the chip select pin nSEL is low. When the nSEL signal is high, it initializes the serial interface. The number of bits sent is an integer multiple of 8. All commands consist of a command code, followed by a varying number of parameter or data bits. All data are sent MSB first (e.g. bit 15 for a 16-bit command). Bits having no influence (don't care) are indicated with X. The Power On Reset (POR) circuit sets default values in all control registers.

The status information or received data can be read serially over the SDO pin. Bits are shifted out upon the falling edge of CLK signal. When the nSEL is high, the SDO output is in a high impedance state.

The receiver will generate an interrupt request (IRQ) for the microcontroller on the following events:

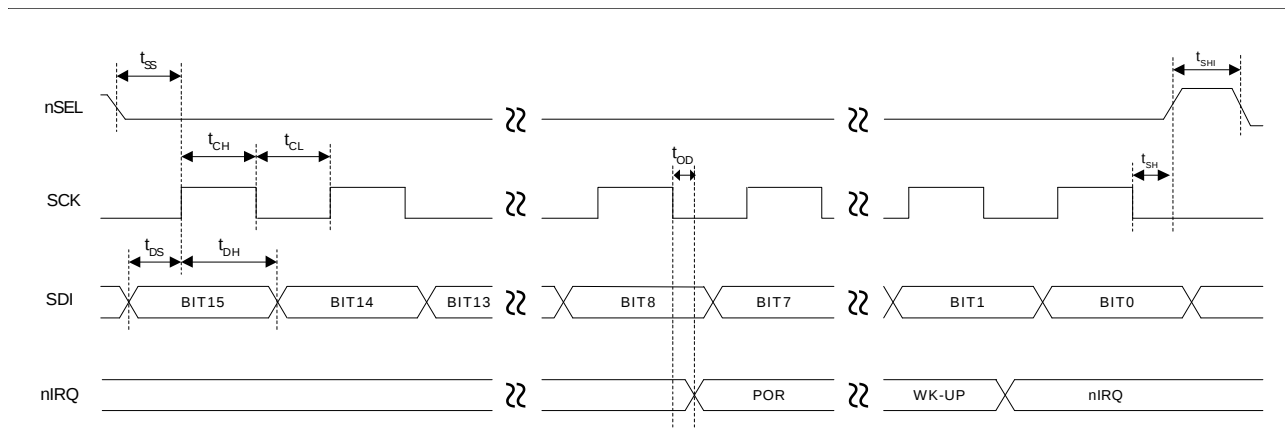
- Supply voltage below the preprogrammed value is detected (LBD)
- Wake-up timer timeout (WK-UP)
- FIFO received the preprogrammed amount of bits (FFIT)
- FIFO overflow (FFOV)

FFIT and FFOV are applicable only when the FIFO is enabled. To find out why the nIRQ was issued, the status bits should be read out.

### Timing Specification

| Symbol    | Parameter                                                | Minimum value [ns] |
|-----------|----------------------------------------------------------|--------------------|
| $t_{CH}$  | Clock high time                                          | 25                 |
| $t_{CL}$  | Clock low time                                           | 25                 |
| $t_{SS}$  | Select setup time (nSEL falling edge to SCK rising edge) | 10                 |
| $t_{SH}$  | Select hold time (SCK falling edge to nSEL rising edge)  | 10                 |
| $t_{SHI}$ | Select high time                                         | 25                 |
| $t_{DS}$  | Data setup time (SDI transition to SCK rising edge)      | 5                  |
| $t_{DH}$  | Data hold time (SCK rising edge to SDI transition)       | 5                  |
| $t_{OD}$  | Data delay time                                          | 10                 |

### Timing Diagram



## Control Commands

|    | Control Word                                   | Related Parameters/Functions                                                                                                      | Related Control Bits                         |
|----|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| 1  | Configuration Setting Command                  | Frequency band, low battery detector, wake-up timer, crystal oscillator load capacitance, baseband filter bandwidth, clock output | b1 to b0, eb, et, ex, x3 to x0, i2 to i0, dc |
| 2  | Frequency Setting Command                      | Set the frequency of the local oscillator                                                                                         | f11 to f0                                    |
| 3  | Receiver Setting Command                       | Set VDI source, LNA gain, RSSI threshold,                                                                                         | d1 to d0, g1 to g0, r2 to r0, en             |
| 4  | Wake-up Timer Command                          | Wake-up time period                                                                                                               | r4 to r0, m7 to m0                           |
| 5  | Low Duty-Cycle Command                         | Set duty-cycle, enable low duty-cycle mode.                                                                                       | d6 to d0, en                                 |
| 6  | Low Battery Detector and Clock Divider Command | Set LBD threshold voltage and microcontroller clock division ratio                                                                | d2 to d0, t4 to t0                           |
| 7  | AFC Control Command                            | Set AFC parameters                                                                                                                | a1 to a0, r11 to r10, st, fi, oe, en         |
| 8  | Data Filter Command                            | Set data filter type, clock recovery parameters                                                                                   | al, ml, s1 to s0, f2 to f0                   |
| 9  | Data Rate Command                              | Bit rate                                                                                                                          | cs, r6 to r0                                 |
| 10 | Output and FIFO Command                        | Set FIFO IT level, FIFO start control, FIFO enable and FIFO fill enable                                                           | f3 to f0, s1 to s0, ff, fe                   |
| 11 | Reset Mode Command                             | Enable / disable sensitive reset                                                                                                  | dr                                           |
| 12 | Status Read Command                            | Read status information                                                                                                           |                                              |

**Note:** In the following tables the POR column shows the default values of the command registers after power-on.

### 1. Configuration Setting Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9  | 8  | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------|
|     | 1  | 0  | 0  | b1 | b0 | eb | et | ex | x3 | x2 | x1 | x0 | i2 | i1 | i0 | dc | 893Ah |

| b1 | b0 | Frequency Band [MHz] |
|----|----|----------------------|
| 0  | 0  | 315                  |
| 0  | 1  | 433                  |
| 1  | 0  | 868                  |
| 1  | 1  | 915                  |

| i2 | i1 | i0 | Baseband Bandwidth [kHz] |
|----|----|----|--------------------------|
| 0  | 0  | 0  | reserved                 |
| 0  | 0  | 1  | 400                      |
| 0  | 1  | 0  | 340                      |
| 0  | 1  | 1  | 270                      |
| 1  | 0  | 0  | 200                      |
| 1  | 0  | 1  | 134                      |
| 1  | 1  | 0  | 67                       |
| 1  | 1  | 1  | reserved                 |

| x3  | x2 | x1 | x0 | Crystal Load Capacitance [pF] |
|-----|----|----|----|-------------------------------|
| 0   | 0  | 0  | 0  | 8.5                           |
| 0   | 0  | 0  | 1  | 9.0                           |
| 0   | 0  | 1  | 0  | 9.5                           |
| 0   | 0  | 1  | 1  | 10.0                          |
| ... |    |    |    |                               |
| 1   | 1  | 1  | 0  | 15.5                          |
| 1   | 1  | 1  | 1  | 16.0                          |

Bits *eb* and *et* control the operation of the low battery detector and wake-up timer, respectively. They are enabled when the corresponding bit is set.

If *ex* is set the crystal is active during sleep mode. When *dc* bit is set it disables the clock output

## 2. Frequency Setting Command

| Bit | 15 | 14 | 13 | 12 | 11  | 10  | 9  | 8  | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|-----|-----|----|----|----|----|----|----|----|----|----|----|-------|
|     | 1  | 0  | 1  | 0  | f11 | f10 | f9 | f8 | f7 | f6 | f5 | f4 | f3 | f2 | f1 | f0 | A680h |

The 12-bit parameter of the *Frequency Setting Command* <f11 : f0> has the value F. The value F should be in the range of 96 and 3903. When F is out of range, the previous value is kept. The synthesizer center frequency  $f_0$  can be calculated as:

$$f_0 = 10 \text{ MHz} * C1 * (C2 + F/4000)$$

The constants C1 and C2 are determined by the selected band as:

| Band [MHz] | C1 | C2 |
|------------|----|----|
| 315        | 1  | 31 |
| 433        | 1  | 43 |
| 868        | 2  | 43 |
| 915        | 3  | 30 |

## 3. Receiver Setting Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 0  | 0  | 0  | 0  | 0 | 0 | d1 | d0 | g1 | g0 | r2 | r1 | r0 | en | C0C1h |

Bits 7-6 select the VDI (valid data indicator) signal:

| d1 | d0 | VDI output                         |
|----|----|------------------------------------|
| 0  | 0  | Digital RSSI Out (DRSSI)           |
| 0  | 1  | Data Quality Detector Output (DQD) |
| 1  | 0  | Clock recovery lock                |
| 1  | 1  | DRSSI && DQD                       |

Bits 5-4 LNA gain set:

| g1 | g0 | G <sub>LNA</sub> (dB relative to max. G) |
|----|----|------------------------------------------|
| 0  | 0  | 0                                        |
| 0  | 1  | -14                                      |
| 1  | 0  | -6                                       |
| 1  | 1  | -20                                      |

Bits 3-1 control the threshold of the RSSI detector:

| r2 | r1 | r0 | RSSI <sub>setth</sub> [dBm] |
|----|----|----|-----------------------------|
| 0  | 0  | 0  | -103                        |
| 0  | 0  | 1  | -97                         |
| 0  | 1  | 0  | -91                         |
| 0  | 1  | 1  | -85                         |
| 1  | 0  | 0  | -79                         |
| 1  | 0  | 1  | -73                         |
| 1  | 1  | 0  | Reserved                    |
| 1  | 1  | 1  | Reserved                    |

The RSSI threshold depends on the LNA gain, the real RSSI threshold can be calculated:

$$\text{RSSI}_{\text{th}} = \text{RSSI}_{\text{setth}} + G_{\text{LNA}}$$

Bit 0 (en) enables the whole receiver chain when set. Enable/disable of the wake-up timer and the low battery detector are not affected by this setting.

**Note:** Clock tail is not generated when the crystal oscillator is controlled by en bit.

#### 4. Wake-Up Timer Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9  | 8  | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 1  | r4 | r3 | r2 | r1 | r0 | m7 | m6 | m5 | m4 | m3 | m2 | m1 | m0 | E196h |

The wake-up time period can be calculated by M <m7 : m0> and R <r4 : r0>:

$$T_{\text{wake-up}} = M * 2^R \text{ ms}$$

Software reset: Sending FF00h command to the chip triggers software reset. For more details see the *Reset modes* section.

#### 5. Low Duty-Cycle Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 0  | 0  | 1  | 1  | 0 | 0 | d6 | d5 | d4 | d3 | d2 | d1 | d0 | en | CC0Eh |

With this command Low Duty-Cycle operation can be set in order to decrease the average power consumption.

The time cycle is determined by the *Wake-Up Timer Command*.

The Duty-Cycle is calculated by D <d6 : d0> and M. (M is parameter in a *Wake-Up Timer Command*.)

$$\text{D.C.} = (D * 2 + 1) / M * 100\%$$

#### 6. Low Battery Detector and Microcontroller Clock Divider Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 0  | 0  | 0  | 0  | 1 | 0 | d2 | d1 | d0 | t4 | t3 | t2 | t1 | t0 | C200h |

The 5-bit value T of t4-t0 determines the threshold voltage of the threshold voltage  $V_{th}$  of the detector:

$$V_{th} = 2.25 \text{ V} + T * 0.1 \text{ V}$$

Clock divider configuration:

| d2 | d1 | d0 | Clock Output Frequency [MHz] |
|----|----|----|------------------------------|
| 0  | 0  | 0  | 1                            |
| 0  | 0  | 1  | 1.25                         |
| 0  | 1  | 0  | 1.66                         |
| 0  | 1  | 1  | 2                            |
| 1  | 0  | 0  | 2.5                          |
| 1  | 0  | 1  | 3.33                         |
| 1  | 1  | 0  | 5                            |
| 1  | 1  | 1  | 10                           |

## 7. AFC Command

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 0  | 0  | 0  | 1  | 1 | 0 | a1 | a0 | r1 | r0 | st | fi | oe | en | C6F7h |

Bit 0 (*en*) enables the calculation of the offset frequency by the AFC circuit (it allows the addition of the content of the output register to the frequency control word of the PLL).

Bit 1 (*oe*) when set, enables the output (frequency offset) register

Bit 2 (*fi*) when set, switches the circuit to high accuracy (fine) mode. In this case the processing time is about four times longer, but the measurement uncertainty is less than half.

Bit 3 (*st*) strobe edge, when *st* goes to high, the actual latest calculated frequency error is stored into the output registers of the AFC block.

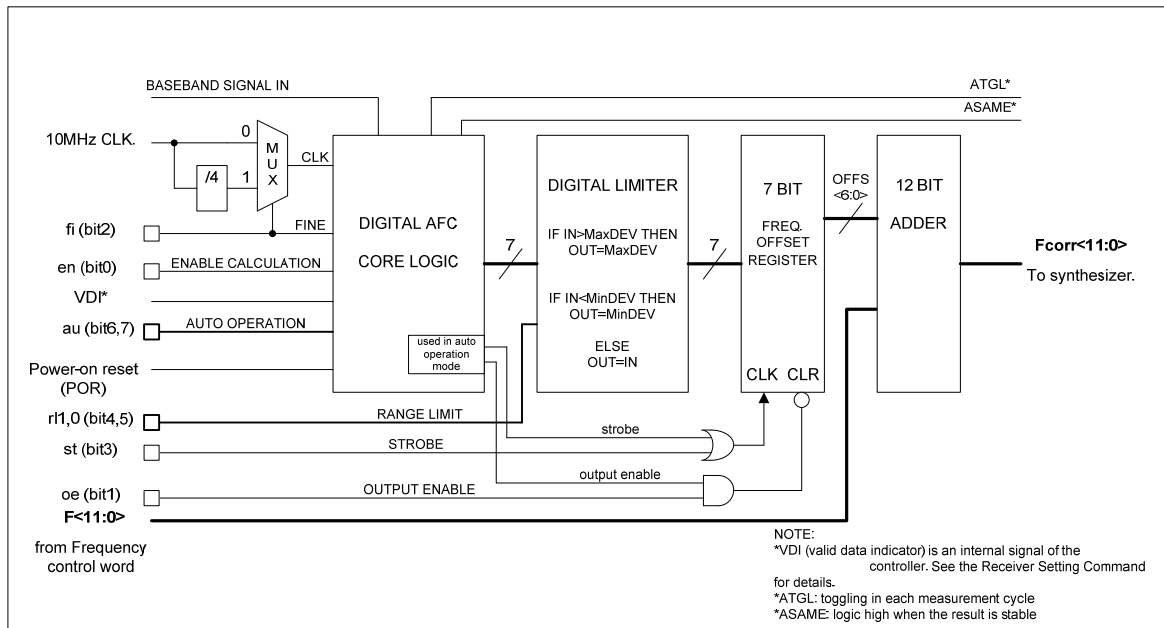
Bit 4-5 (*r0*, *r1*) range limit: Limits the value of the frequency offset register to the following values:

| r1 | r0 | Max dev [ $f_{res}$ ] |
|----|----|-----------------------|
| 0  | 0  | No restriction        |
| 0  | 1  | +15/-16               |
| 1  | 0  | +7/-8                 |
| 1  | 1  | +3/-4                 |

$f_{res}$ :  
 315, 433MHz bands: 2.5kHz  
 868MHz band: 5kHz  
 915MHz band: 7.5kHz

Bit 6-7 (*a0*, *a1*) Automatic operation mode selector:

| a1 | a0 | Automatic operation mode                                                   |
|----|----|----------------------------------------------------------------------------|
| 0  | 0  | Auto mode off (Strobe is controlled by microcontroller)                    |
| 0  | 1  | Runs only once after each power-up                                         |
| 1  | 0  | Drop the $f_{offset}$ value when the VDI signal is low                     |
| 1  | 1  | Keep the $f_{offset}$ value independently from the state of the VDI signal |



In automatic operation mode (no strobe signal is needed from the microcontroller to update the output offset register), the AFC circuit is automatically enabled when VDI indicates a potential incoming signal during the whole measurement cycle and the circuit measures the same result in two subsequent cycles.

There are three operation modes, example from the possible application:

1, ( $a1=0$ ,  $a0=1$ ) The circuit measures the frequency offset only once after power up. This way, the extended TX/RX maximum distance can be achieved. Possible usage: In the final application when the user is inserted the battery the circuit measures and compensate the frequency offset caused by the crystal tolerances. This method enables to use cheaper quartz in the application and provide quite good protection against locking in an interferer.

2a, ( $a1=1$ ,  $a0=0$ ) The circuit measures automatically the frequency offset during an initial low data rate pattern –easier to receive- (i.e.: 00110011) of the package and change the receiving frequency according that. The further part of the package can be received by the corrected frequency settings.

2b, ( $a1=1$ ,  $a0=0$ ) The transmitter must transmit the first part of the packet with a step higher deviation and later there is a possibility to reduce it.

In both cases (2a and 2b) when the VDI indicates poor receiving conditions (VDI goes low) the output register is automatically cleared. It's suggested to use when one receiver receives signal from more than one transmitter.

3, ( $a1=1$ ,  $a0=1$ ) It is similar to the 2a and 2b modes, but 3 is suggested to use when a receiver operates with only one transmitter. After a complete measuring cycle, the measured value is held independently of the state of VDI signal.

## 8. Data Filter Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5 | 4  | 3  | 2  | 1  | 0  |              |
|-----|----|----|----|----|----|----|---|---|----|----|---|----|----|----|----|----|--------------|
|     | 1  | 1  | 0  | 0  | 0  | 1  | 0 | 0 | al | ml | 1 | s1 | s0 | f2 | f1 | f0 | POR<br>C42Ch |

Bit 7 <al>: Clock recovery (CR) auto lock control if set.

It means that the CR start in fast mode after locking it automatically switches to slow mode.

Bit 6 <ml>: Clock recovery lock control

1: fast mode, fast attack and fast release

0: slow mode, slow attack and slow release

Using the slower one requires more accurate bit timing (see Data Rate Command).

Bit 3-4 <s0 : s1>: Select the type of the data filter:

| s1 | s0 | Filter Type      |
|----|----|------------------|
| 0  | 0  | OOK to filter    |
| 0  | 1  | Digital filter   |
| 1  | 0  | Reserved         |
| 1  | 1  | Analog RC filter |

OOK to filter: the analog RSSI signal is used as received data. The DRSSI threshold level is used for slicing.

Digital: this is a digital realization of an analog RC filter followed by a comparator with hysteresis. The time constant is automatically adjusted to the bit rate defined by the Data Rate Command.

Analog RC filter: The demodulator output is fed to pin 7 over a 10 kOhm resistor. The filter cut-off frequency is set by the external capacitor connected to this pin and VSS.

The table shows the optimal filter capacitor values for different data rates:

| 1.2 kbps | 2.4 kbps | 4.8 kbps | 9.6 kbps | 19.2 kbps | 38.4 kbps | 57.6 kbps | 115.2 kbps | 256 kbps |
|----------|----------|----------|----------|-----------|-----------|-----------|------------|----------|
| 12 nF    | 8.2 nF   | 6.8 nF   | 3.3 nF   | 1.5 nF    | 680 pF    | 270 pF    | 150 pF     | 100 pF   |

**Note:** If analog RC filter is selected the internal clock recovery circuit and the FIFO cannot be used.

Bit 0-2 <f0 : f2>: DQD threshold parameter.

**Note:** To let the DQD report "good signal quality" the threshold parameter should be less than 4 in the case when the bitrate is close to the deviation. At higher deviation/bitrate settings higher threshold parameter can report "good signal quality" as well.

## 9. Data Rate Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 0  | 0  | 1  | 0  | 0 | 0 | cs | r6 | r5 | r4 | r3 | r2 | r1 | r0 | C823h |

The expected bit rate of the received data stream is determined by the 7-bit value R (bits r6 to r0) and the 1 bit cs.

$$BR = 10 \text{ MHz} / 29 / (R+1) / (1 + cs*7)$$

In the receiver set R according the next function:

$$R = (10 \text{ MHz} / 29 / (1 + cs*7) / BR) - 1$$

Apart from setting custom values, the standard bit rates from 600 bps to 115.2 kbps can be approximated with small error.

Data rate accuracy requirements:

$$\text{Clock recovery in slow mode: } \Delta BR / BR < 1 / (29 * N_{\text{bit}})$$

$$\text{Clock recovery in fast mode: } \Delta BR / BR < 3 / (29 * N_{\text{bit}})$$

BR is the bit rate set in the receiver and  $\Delta BR$  is bit rate difference between the transmitter and the receiver.  $N_{\text{bit}}$  is the maximal number of consecutive ones or zeros in the data stream. It is recommended for long data packets to include enough 1/0 and 0/1 transitions, and be careful to use the same division ratio in the receiver and in the transmitter.

$\Delta BR$  is a theoretical limit for the clock recovery circuit. Clock recovery will not work above this limit. The clock recovery circuit will always operate below this limit independently from process, temperature, or  $V_{\text{dd}}$  condition.

Supposing a maximum length of consecutive zeros or ones in the data stream is less than 5 bits, the necessary relative accuracy is 0.68% in slow mode and 2.1% in fast mode.

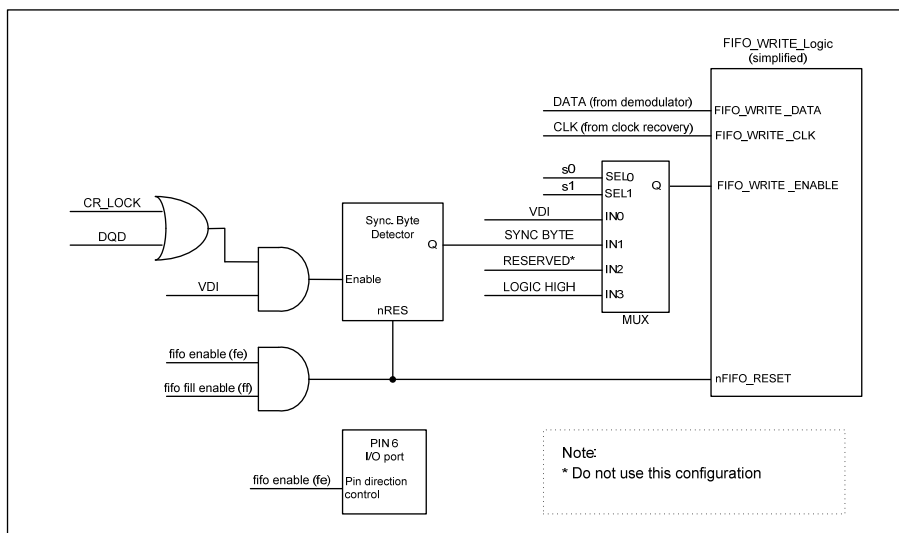
## 10. Output and FIFO Mode Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|----|----|----|----|----|----|----|----|-------|
|     | 1  | 1  | 0  | 0  | 1  | 1  | 1 | 0 | f3 | f2 | f1 | f0 | s1 | s0 | ff | fe | CE85h |

Bit 4-7 <f3 : f0>: FIFO IT level. The FIFO generates IT when number of the received data bits reaches this level.

Bit 2-3 <s1 : s0>: Set the input of the FIFO fill start condition:

| s1 | s0 | FIFO fill start condition |
|----|----|---------------------------|
| 0  | 0  | VDI                       |
| 0  | 1  | Sync Word                 |
| 1  | 0  | Reserved                  |
| 1  | 1  | Always                    |



**Note:** VDI (Valid Data Indicator) see further details in *Receiver Control Word*, Synchron word in microcontroller mode is 2DD4h.

Bit 1: <ff> Enables FIFO fill after synchron word reception. FIFO fill stops when this bit is cleared.

Bit 0: <fe> Enables the 16bit deep FIFO mode. To clear the FIFO's counter and content, it has to be set zero.

**Note:** To restart the synchron word reception, bit 1 should be cleared and set. This action will initialize the FIFO and clear its content.

Bit 0 modifies the function of pin 6 and pin 7. Pin 6 (nFFS) will become input if fe is set to 1. If the chip is used in FIFO mode, do not allow this to be a floating input.

### 11. Reset Mode Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0  | POR   |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|----|-------|
|     | 1  | 1  | 0  | 1  | 1  | 0  | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | dr | DA00h |

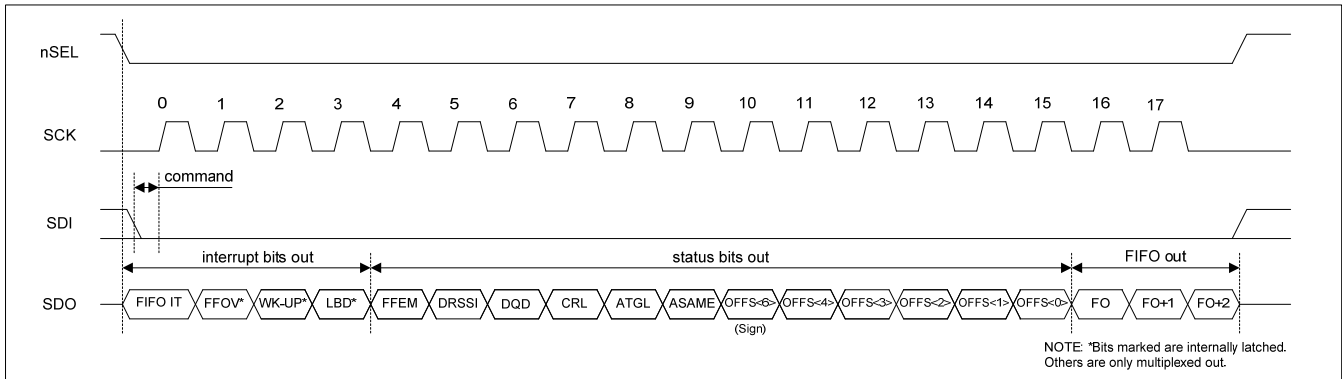
Bit 0 (dr): Disables the highly sensitive RESET mode. If this bit is cleared, a 600 mV glitch in the power supply may cause a system reset. For more detailed description see the *Reset modes* section.

### 12. Status Read Command

| bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | POR |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|-----|
|     | 0  | 0  | 0  | 0  | 0  | 0  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | --  |

The read command starts with a zero, whereas all other control commands start with a one. Therefore, after receiving the first bit of the control command the Si4320 identifies it as a read command. So as the first bit of the command is received, the receiver starts to clock out the status bits on the SDO output as follows:

#### Status Register Read Sequence with FIFO Read Example



It is possible to read out the content of the FIFO after the reading of the status bits. The command can be aborted after any read bits by rising edge of the select signal.

**Note:** The FIFO IT bit behaves like a status bit, but generates nIRQ pulse if active. To check whether there is a sufficient amount of data in the FIFO, the SDO output can be tested. In extreme speed critical applications, it can be useful to read only the first four bits (FIFO IT - LBD) to clear the FFOV, WK-UP, and LBD bits. During the FIFO access the  $f_{SCK}$  cannot be higher than  $f_{ref}/4$ , where  $f_{ref}$  is the crystal oscillator frequency. If the FIFO is read in this mode the nFFS input must be connected to logic high level.

Definitions of the bits in the above timing diagram:

|            |                                                                               |
|------------|-------------------------------------------------------------------------------|
| FIFO IT    | Number of the data bits in the FIFO is reached the preprogrammed limit        |
| FFOV       | FIFO overflow                                                                 |
| WK-UP      | Wake-up timer overflow                                                        |
| LBD        | Low battery detect, the power supply voltage is below the preprogrammed limit |
| FFEM       | FIFO is empty                                                                 |
| DRSSI      | The strength of the incoming signal is above the preprogrammed limit          |
| DQD        | Data Quality Detector detected a good quality signal                          |
| CRL        | Clock recovery lock                                                           |
| ATGL       | Toggling in each AFC cycle                                                    |
| ASAME      | AFC stabilized (measured twice the same offset value)                         |
| OFFS6, 4-0 | Offset value to be added to the value of the Frequency control word           |

### FIFO Buffered Data Read

In this operating mode, incoming data are clocked into a 16 bit FIFO buffer. The receiver starts to fill up the FIFO when the Valid Data Indicator (VDI) bit and/or the synchron word recognition circuit indicates potentially real incoming data. This prevents the FIFO from being filled with noise and overloading the external microcontroller.

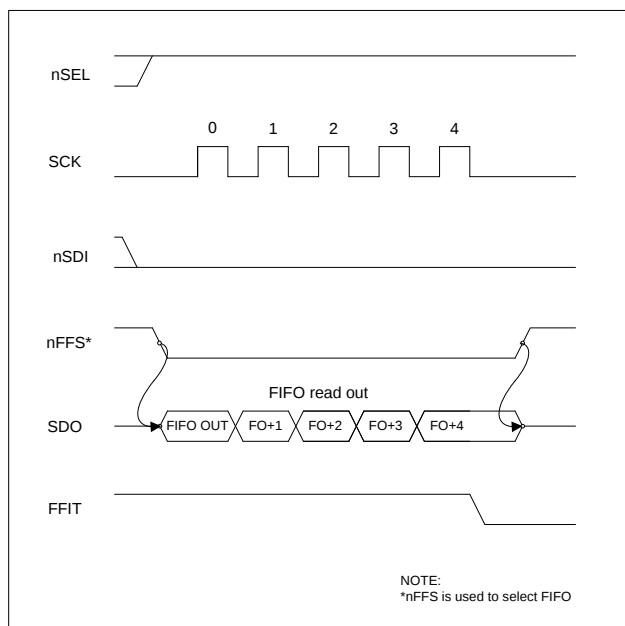
For further details see the *Receiver Setting Command* and the *Output and FIFO Command*.

#### Polling Mode:

The nFFS signal selects the buffer directly and its content could be clocked out through pin SDO by SCK. Set the FIFO IT level to 1. In this case, as long as FFIT indicates received bits in the FIFO, the controller may continue to take the bits away. When FFIT goes low, no more bits need to be taken. An SPI read command is also available.

#### Interrupt Controlled Mode:

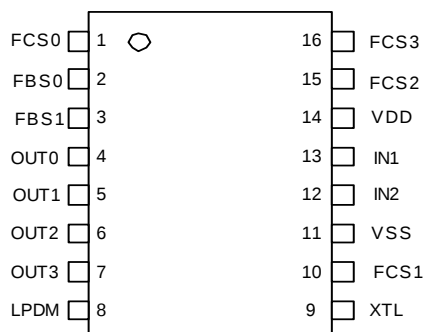
The user can define the FIFO level (the number of received bits) which will generate the nFFIT when exceeded. The status bits report the changed FIFO status in this case.



During FIFO access the  $f_{SCK}$  cannot be higher than  $f_{ref}/4$ , where  $f_{ref}$  is the crystal oscillator frequency.

## STANDALONE OPERATION

The chip supports standalone operation, meaning that with preprogrammed (hard wired) parameters, a simple receiver can be built without an external microcontroller. After the power-up sequence, the status of pin 8 is queried by connecting internally about 10  $\mu$ A current on it. If VSS or VDD is detected, the chip turns to standalone mode. In this case 7 pins are used to configure the receiver and 4 digital outputs are available:



In the standalone mode, a predefined data sequence should be employed which contains preamble, synchron, chip address, and function control bytes. To allow the control of the outputs, the chip should receive its chip address byte and twice the same function control byte.

The required data flow sequence:

| Preamble Byte | Synchron Byte | Chip Address Byte        | Function Control Byte | One's complement of Function Control Byte | Function Control Byte |
|---------------|---------------|--------------------------|-----------------------|-------------------------------------------|-----------------------|
| AAh           | 2Dh           | D4h<br>D2h<br>B4h<br>B2h | See below             | See below                                 | See below             |

As a minimum preamble, use at least 16 bits.

The structure of the Function Control Byte is shown below. For each output there are two bits assigned to define their mode of operation:

|            |            |            |            |            |            |            |            |
|------------|------------|------------|------------|------------|------------|------------|------------|
| OUT3<br>F1 | OUT3<br>F0 | OUT2<br>F1 | OUT2<br>F0 | OUT1<br>F1 | OUT1<br>F0 | OUT0<br>F1 | OUT0<br>F0 |
|------------|------------|------------|------------|------------|------------|------------|------------|

OUT3 / F1 sent out first., OUT0 – OUT3 represent the four digital output pins, F0 - F1 represents the function bits.

Output functions controlled by the function bits, as follows:

| F1 | F0 | Function                                                   |
|----|----|------------------------------------------------------------|
| 0  | 0  | No change                                                  |
| 0  | 1  | Sets output logical low                                    |
| 1  | 0  | Sets output logical high                                   |
| 1  | 1  | Sets output high in mono-stable mode, cycle time is 100 ms |

Mono-stable mode will be restarted as long as the proper *Function Control Byte* is received.

The following receiving frequencies can be set with the different static external pin settings:

| PIN16<br>FCS3 | PIN15<br>FCS2 | PIN10<br>FCS1 | PIN1<br>FCS0 | F <sub>receiving</sub><br>PIN2=0<br>PIN3=0 | F <sub>receiving</sub><br>PIN2=1<br>PIN3=0 | F <sub>receiving</sub><br>PIN2=0<br>PIN3=1 | F <sub>receiving</sub><br>PIN2=1<br>PIN3=1 | Chip Address<br>Byte |
|---------------|---------------|---------------|--------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|----------------------|
| 0             | 0             | 0             | 0            | 310.320                                    | 433.360                                    | (867.680)                                  | (900.960)                                  | D4h                  |
| 0             | 0             | 0             | Z or 1       | 310.960                                    | 433.440                                    | (867.840)                                  | 902.880                                    | D2h                  |
| 0             | 0             | Z             | 0            | 311.600                                    | 433.520                                    | (868.000)                                  | 904.800                                    | B4h                  |
| 0             | 0             | Z             | Z or 1       | 312.240                                    | 433.600                                    | 868.160                                    | 906.720                                    | B2h                  |
| 0             | Z             | 0             | 0            | 312.880                                    | 433.680                                    | 868.320                                    | 908.640                                    | D4h                  |
| 0             | Z             | 0             | Z or 1       | 313.520                                    | 433.760                                    | 868.480                                    | 910.560                                    | D2h                  |
| 0             | Z             | Z             | 0            | 314.160                                    | 433.840                                    | 868.640                                    | 912.480                                    | B4h                  |
| 0             | Z             | Z             | Z or 1       | 314.800                                    | 433.920                                    | 868.800                                    | 914.400                                    | B2h                  |
| Z             | 0             | 0             | 0            | 315.440                                    | 434.000                                    | 868.960                                    | 916.320                                    | D4h                  |
| Z             | 0             | 0             | Z or 1       | 316.080                                    | 434.080                                    | 869.120                                    | 918.240                                    | D2h                  |
| Z             | 0             | Z             | 0            | 316.720                                    | 434.160                                    | 869.280                                    | 920.160                                    | B4h                  |
| Z             | 0             | Z             | Z or 1       | 317.360                                    | 434.240                                    | 869.440                                    | 922.080                                    | B2h                  |
| Z             | Z             | 0             | 0            | 318.000                                    | 434.320                                    | 869.600                                    | 924.000                                    | D4h                  |
| Z             | Z             | 0             | Z or 1       | 318.640                                    | 434.400                                    | 869.760                                    | 925.920                                    | D2h                  |
| Z             | Z             | Z             | 0            | 319.280                                    | 434.480                                    | 869.920                                    | 927.840                                    | B4h                  |
| Z             | Z             | Z             | Z or 1       | 319.920                                    | 434.560                                    | (870.080)                                  | (929.760)                                  | B2h                  |

**Note 1:** Z: Not connected (floating) pin

**Note 2:** Values shown as *(italic)* are out-of-band frequencies.

**Note 3:** If FCS0=1 (connected to VDD) the RSSI threshold limit is changed from -103 dBm to -97 dBm.

**Note 4:** In standalone mode, the operation parameters related to the band, frequency selection and chip address are determined by the table above. All other control bits (filter bandwidth, bit rate etc.) are determined by the power-on values of the different control registers.

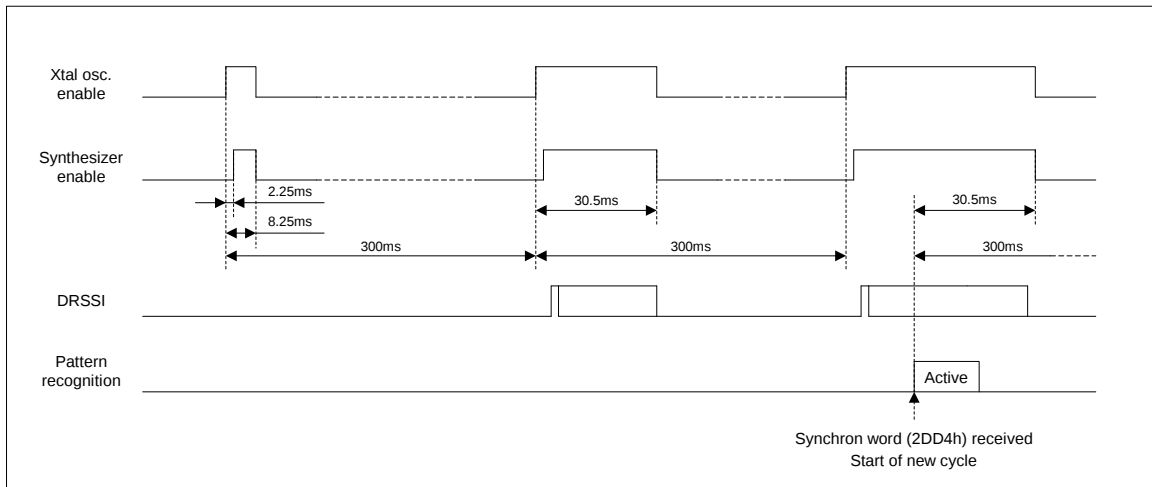
**Note 5:** It is possible to use the receiver in a so-called "mixed mode". The SPI bus architecture allows access to the bus in standalone mode (pins 1, 2, 3) and thereby makes it possible to overwrite the default POR values of the control registers. In this way the operating parameters of the receiver can be programmed over the interface while performing the functions of the standalone mode when receiving the proper data sequence.

## Low Power Duty-Cycle Operation (LPDM)

To use this mode, pin 8 must be connected to VDD. The logic value of pin 8 defines whether the receiver works in *Low Power Duty-Cycle Mode* (LPDM) or not. If the value is high (VDD detected), the chip will wake up in every 300 ms. If the value is low (GND detected), then the chip is continually ON (active). The chip uses the internal wake-up timer and counter for timing the on/off process. This method reduces the overall current consumption, which should permit approximately 6 months operation from a 1500 mAh battery.

## Low Power Duty-Cycle Internal Operations and Timings (Wake-up on Radio)

The wake-up timer event switches on the crystal oscillator, the internal logic waits about 2.25ms. When the oscillator is stable the controller switches on the synthesizer as well. The receiver monitors the incoming signal strength during this "ON" state of LPDM. If in the next 6ms the incoming signal strength is above the defined limit (-103dBm if FCS0=0 or -97dBm if FCS0=1), the synthesizer remains switched on for 30.5ms, otherwise it switches itself off after the 6ms operation time. The period time is about 300ms.



**Note 1:** Every detected synchron word restarts the timer, which controls the 'ON' state of the receiver.

**Note 2:** If the internal *Pattern Recognition* block is active (decoding the synchron word), then the internal logic does not switch the synthesizer off until the incoming data is fully processed.

## RX-TX ALIGNMENT PROCEDURES

RX-TX frequency offset can be caused only by the differences in the actual reference frequency. To minimize these errors it is suggested to use the same crystal type and the same PCB layout for the crystal placement on the RX and TX PCBs.

To verify the possible RX-TX offset it is suggested to measure the CLK output of both chips with a high level of accuracy. Do not measure the output at the XTL pin since the measurement process itself will change the reference frequency. Since the carrier frequencies are derived from the reference frequency, having identical reference frequencies and nominal frequency settings at the TX and RX side there should be no offset if the CLK signals have identical frequencies.

It is possible to monitor the actual RX-TX offset using the AFC status report included in the status byte of the receiver. By reading out the status byte from the receiver, the actual measured offset frequency will be reported. In order to get accurate values the AFC has to be disabled during the read by clearing the "en" bit in the AFC Control Command (bit 0).

## CRYSTAL SELECTION GUIDELINES

The crystal oscillator of the Si4320 requires a 10 MHz parallel mode crystal. The circuit contains an integrated load capacitor in order to minimize the external component count. The internal load capacitance value is programmable from 8.5 pF to 16 pF in 0.5 pF steps. With appropriate PCB layout, the total load capacitance value can be 10 pF to 20 pF so a variety of crystal types can be used.

When the total load capacitance is not more than 20 pF and a worst case 7 pF shunt capacitance ( $C_0$ ) value is expected for the crystal, the oscillator is able to start up with any crystal having less than 300 ohms ESR (equivalent series loss resistance). However, lower  $C_0$  and ESR values guarantee faster oscillator startup.

The crystal frequency is used as the reference of the PLL, which generates the local oscillator frequency ( $f_{LO}$ ). Therefore,  $f_{LO}$  is directly proportional to the crystal frequency. The accuracy requirements for production tolerance, temperature drift and aging can thus be determined from the maximum allowable local oscillator frequency error.

### Maximum XTAL Tolerances Including Temperature and Aging [ppm]

| Bit Rate: 2.4kbps | Transmitter Deviation [± kHz] |    |     |     |     |     |     |
|-------------------|-------------------------------|----|-----|-----|-----|-----|-----|
|                   | 30                            | 60 | 90  | 120 | 150 | 180 | 210 |
| 315 MHz           | 30                            | 75 | 100 | 100 | 100 | 100 | 100 |
| 433 MHz           | 20                            | 50 | 75  | 100 | 100 | 100 | 100 |
| 868 MHz           | 10                            | 25 | 40  | 60  | 75  | 100 | 100 |
| 915 MHz           | 10                            | 25 | 40  | 50  | 75  | 75  | 100 |

| Bit Rate: 9.6kbps | Transmitter Deviation [± kHz] |    |     |     |     |     |     |
|-------------------|-------------------------------|----|-----|-----|-----|-----|-----|
|                   | 30                            | 60 | 90  | 120 | 150 | 180 | 210 |
| 315 MHz           | 25                            | 70 | 100 | 100 | 100 | 100 | 100 |
| 433 MHz           | 15                            | 50 | 75  | 100 | 100 | 100 | 100 |
| 868 MHz           | 8                             | 25 | 40  | 60  | 75  | 75  | 100 |
| 915 MHz           | 8                             | 25 | 40  | 50  | 70  | 75  | 100 |

| Bit Rate: 38.3kbps | Transmitter Deviation [± kHz] |    |    |     |     |     |     |
|--------------------|-------------------------------|----|----|-----|-----|-----|-----|
|                    | 30                            | 60 | 90 | 120 | 150 | 180 | 210 |
| 315 MHz            | don't use                     | 30 | 75 | 100 | 100 | 100 | 100 |
| 433 MHz            | don't use                     | 20 | 50 | 75  | 100 | 100 | 100 |
| 868 MHz            | don't use                     | 10 | 30 | 40  | 60  | 75  | 100 |
| 915 MHz            | don't use                     | 10 | 25 | 40  | 60  | 75  | 75  |

Whenever a low frequency error is essential for the application, it is possible to “pull” the crystal to the accurate frequency by changing the load capacitor value. The widest pulling range can be achieved if the nominal required load capacitance of the crystal is in the “midrange”, for example 16 pF. The “pull-ability” of the crystal is defined by its motional capacitance and  $C_0$ .

The on chip AFC is capable to correct TX/RX carrier offsets as much as 80% of the deviation of the received FSK modulated signal.

**Note:** There may be other requirements for the TX carrier accuracy with regards to the requirements as defined by standards and/or channel separations.

## RESET MODES

The chip will enter into reset mode if any of the following conditions are met:

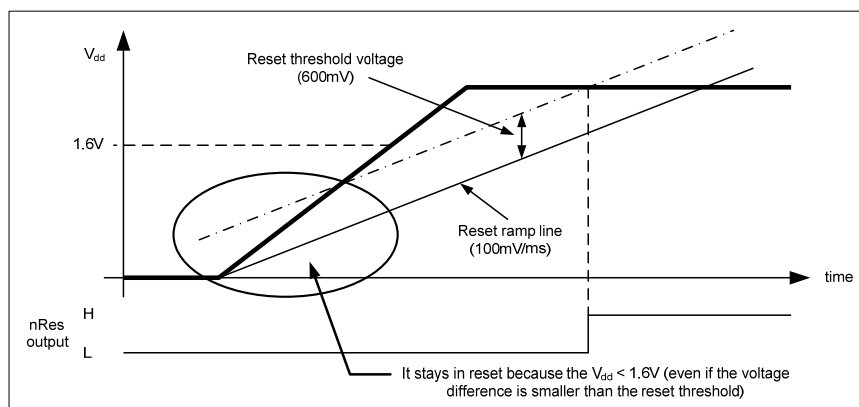
- Power-on reset: During a power up sequence until the  $V_{dd}$  has reached the correct level and stabilized
- Power glitch reset: Transients present on the  $V_{dd}$  line
- Software reset: Special control command received by the chip

### Power-on reset

After power up the supply voltage starts to rise from 0V. The reset block has an internal ramping voltage reference (reset-ramp signal), which is rising at 100mV/ms (typical) rate. The chip remains in reset state while the voltage difference between the actual  $V_{dd}$  and the internal reset-ramp signal is higher than the reset threshold voltage, which is 600 mV (typical). As long as the  $V_{dd}$  voltage is less than 1.6V (typical) the chip stays in reset mode regardless the voltage difference between the  $V_{dd}$  and the internal ramp signal.

The reset event can last up to 150ms supposing that the  $V_{dd}$  reaches 90% its final value within 1ms. During this period the chip does not accept control commands via the serial control interface.

Power-on reset example:



### Power glitch reset

The internal reset block has two basic mode of operation: normal and sensitive reset. The default mode is sensitive, which can be changed by the appropriate control command (see *Related control commands* at the end of this section). In normal mode the power glitch detection circuit is disabled.

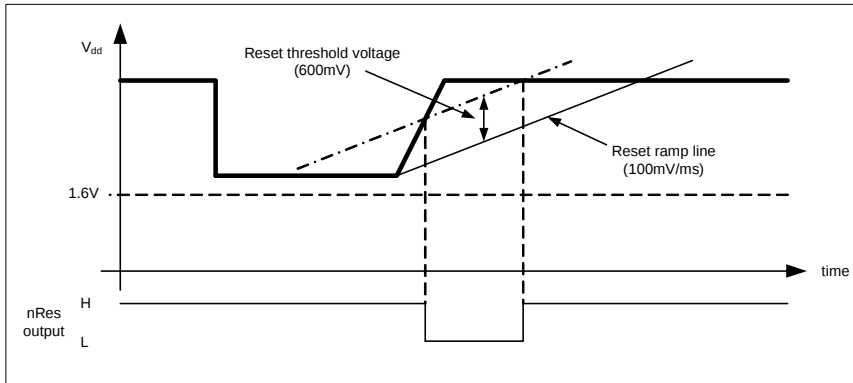
There can be spikes or glitches on the  $V_{dd}$  line if the supply filtering is not satisfactory or the internal resistance of the power supply is too high. In such cases if the sensitive reset is enabled an (unwanted) reset will be generated if the positive going edge of the  $V_{dd}$  has a rising rate greater than 100mV/ms and the voltage difference between the internal ramp signal and the  $V_{dd}$  reaches the reset threshold voltage (600 mV). Typical case when the battery is weak and due to its increased internal resistance a sudden decrease of the current consumption (for example turning off the power amplifier) might lead to an increase in supply voltage. If for some reason the sensitive reset cannot be disabled step-by-step decrease of the current consumption (by turning off the different stages one by one) can help to avoid this problem.

Any negative change in the supply voltage will not cause reset event unless the  $V_{dd}$  level reaches the reset threshold voltage (250mV in normal mode, 1.6V in sensitive reset mode).

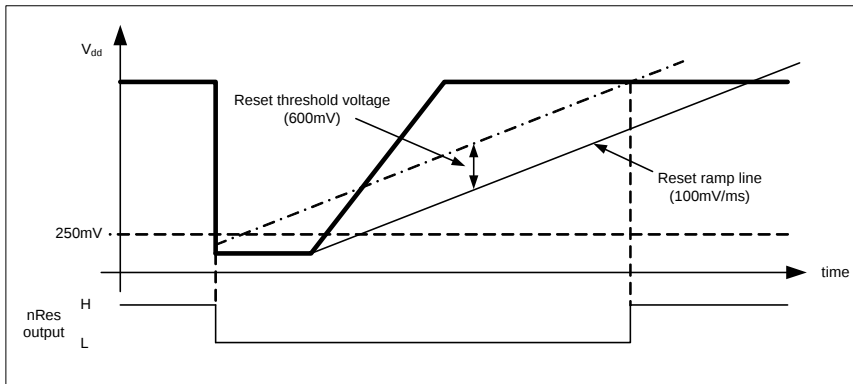
If the sensitive mode is disabled and the power supply turned off the  $V_{dd}$  must drop below 250mV in order to trigger a power-on reset event when the supply voltage is turned back on. If the decoupling capacitors keep their charges for a long time it could happen that no reset will be generated upon power-up because the power glitch detector circuit is disabled.

Note that the reset event reinitializes the internal registers, so the sensitive mode will be enabled again.

Sensitive Reset Enabled, Ripple on  $V_{dd}$ :



Sensitive reset disabled:



### Software reset

Software reset can be issued by sending the appropriate control command (described at the end of the section) to the chip. The result of the command is the same as if power-on reset was occurred. When the nRES pin connected to the reset pin of the microcontroller, using the software reset command may cause unexpected problems.

### $V_{dd}$ line filtering

During the reset event (caused by power-on, fast positive spike on the supply line or software reset command) it is very important to keep the  $V_{dd}$  line as smooth as possible. Noise or periodic disturbing signal superimposed the supply voltage may prevent the part getting out from reset state. To avoid this phenomenon use adequate filtering on the power supply line to keep the level of the disturbing signal below 10mV<sub>p-p</sub> in the DC – 50kHz range for 200ms from  $V_{dd}$  ramp start.. Typical example when a switch-mode regulator is used to supply the radio, switching noise may be present on the  $V_{dd}$  line. Follow the manufacturer's recommendations how to decrease the ripple of the regulator IC and/or how to shift the switching frequency.

### Related control commands

#### "Reset Mode Command"

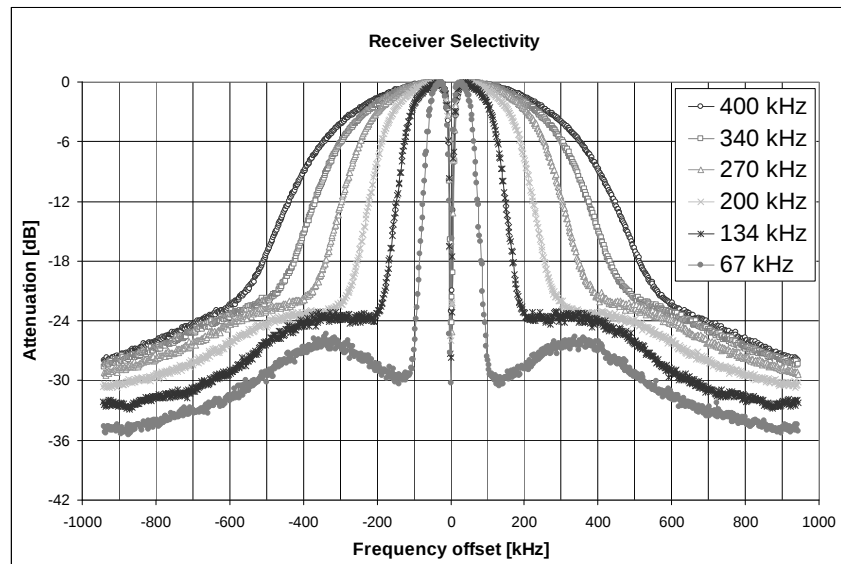
Setting bit<0> to high will change the reset mode to normal from the default sensitive.

#### "SW Reset Command"

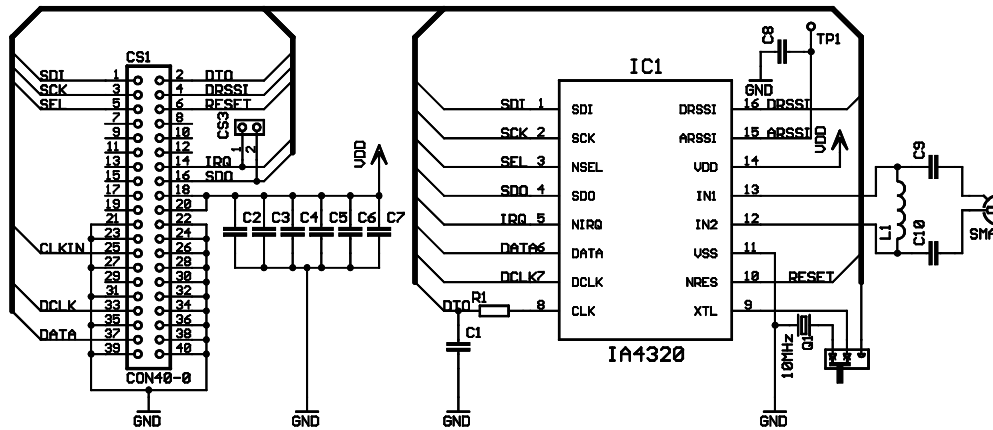
Issuing FF00h command will trigger software reset. See the *Wake-up Timer Command*.

## MEASUREMENT RESULTS

### Receiver Selectivity at Different Baseband Filter Settings

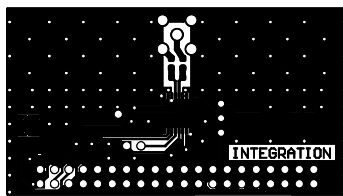


## Measurement Setup

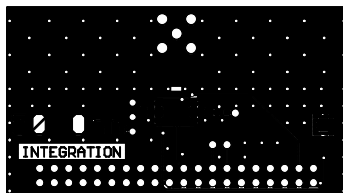


A group of decoupling capacitors is placed to provide very low supply noise for the measurements. R1-C1 forms a low pass filter to block the CLK signal going down to the test-board on pin 2 of the connector.

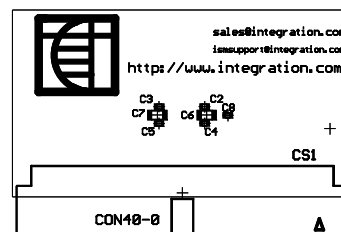
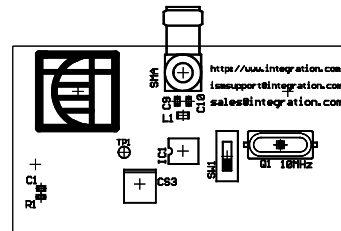
## Layout and Assembly Drawing for the 50 $\Omega$ Test-Board



Top Layer

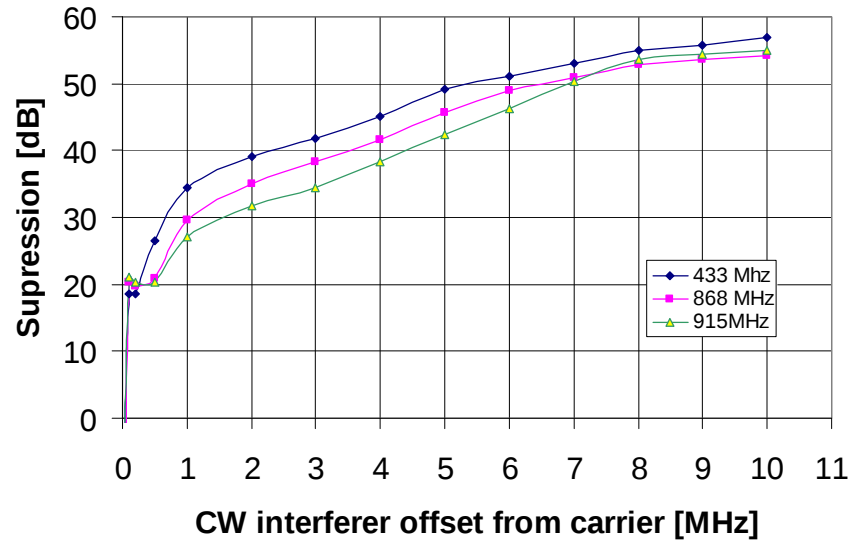


Bottom Layer



## TYPICAL PERFORMANCE CHARACTERISTICS

### Channel Selectivity and Blocking

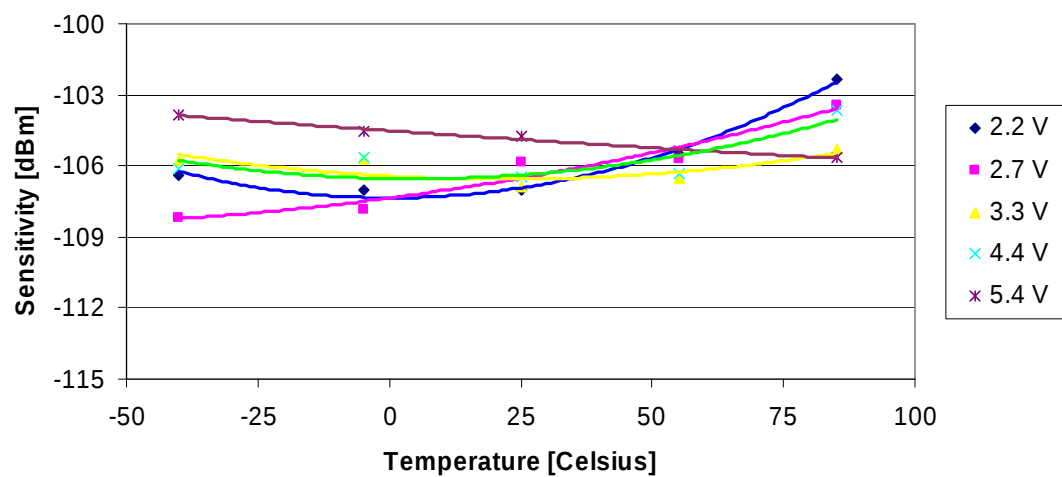


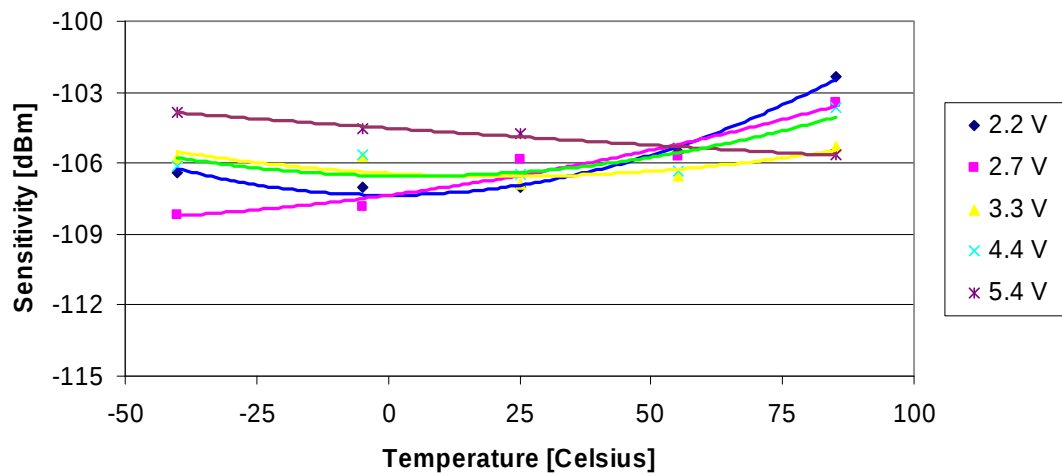
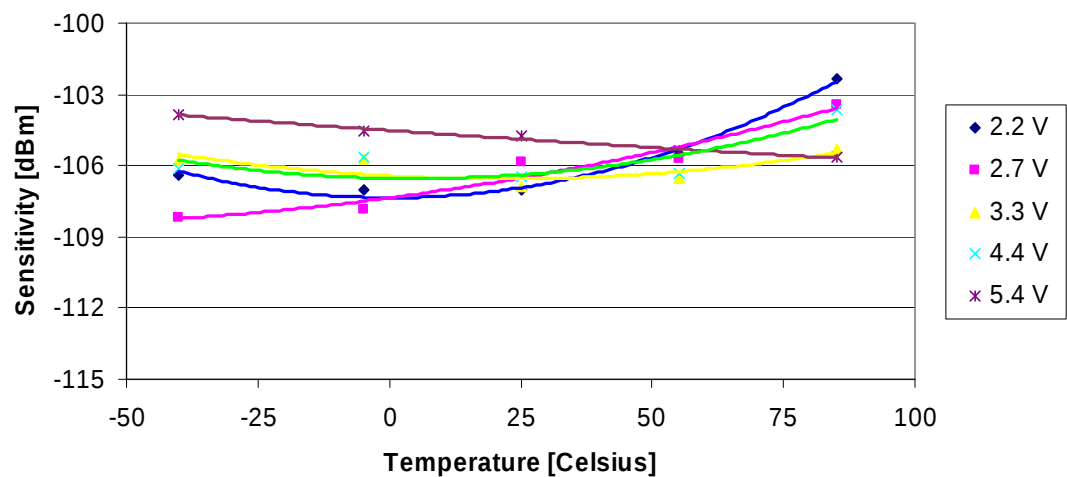
**Note:**

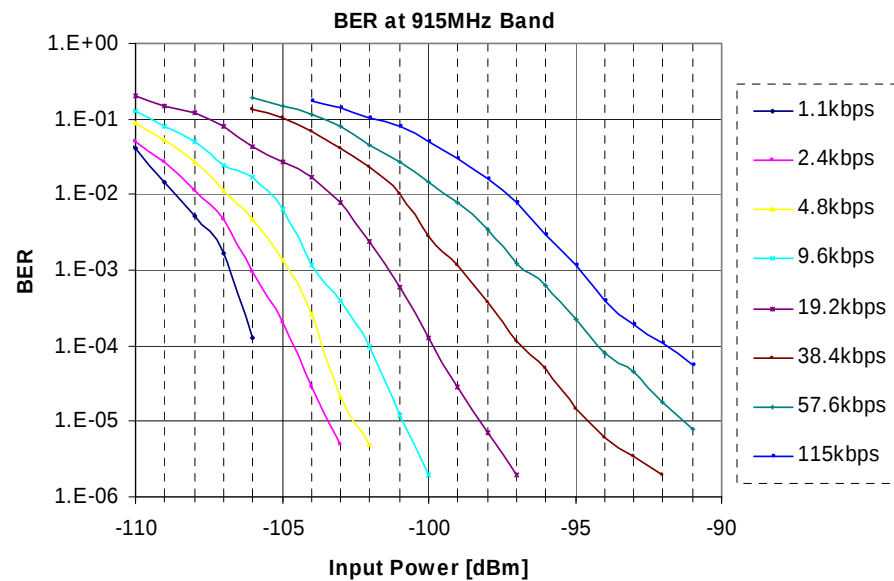
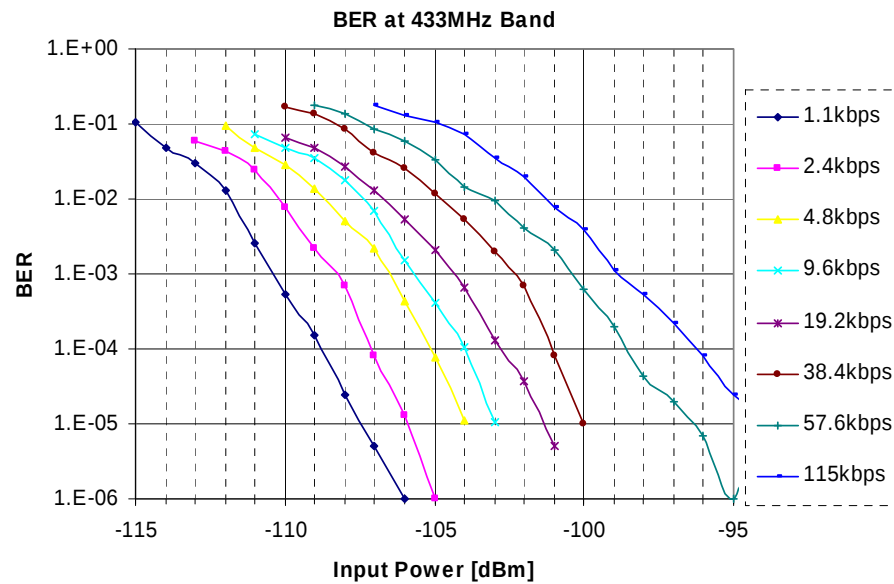
- LNA gain maximum, filter bandwidth 67 kHz, data rate 9.6 kbps, AFC switched off, FSK deviation +/- 45 kHz,  $V_{dd}$  3V,
- Measured in compliant with ETSI Standard EN 300 220-1 v2.1.1 (2006-01 Final Draft), section 9

### Sensitivity over Ambient Temperature (868 MHz, 9.6 kbps, dfsk: 45 kHz, BW: 67 kHz)

#### 868 MHz

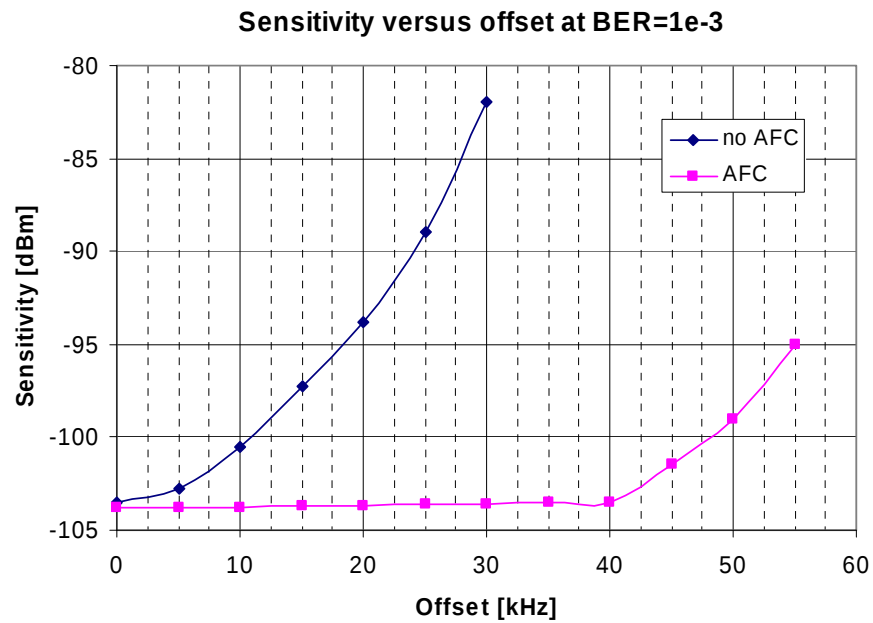


**Sensitivity over Ambient Temperature (434 MHz, 9.6 kbps, dfsk: 45 kHz, BW: 67 kHz)****434 MHz****Sensitivity over Ambient Temperature (915 MHz, 9.6 kbps, dfsk: 45 kHz, BW: 67 kHz)****915 MHz**

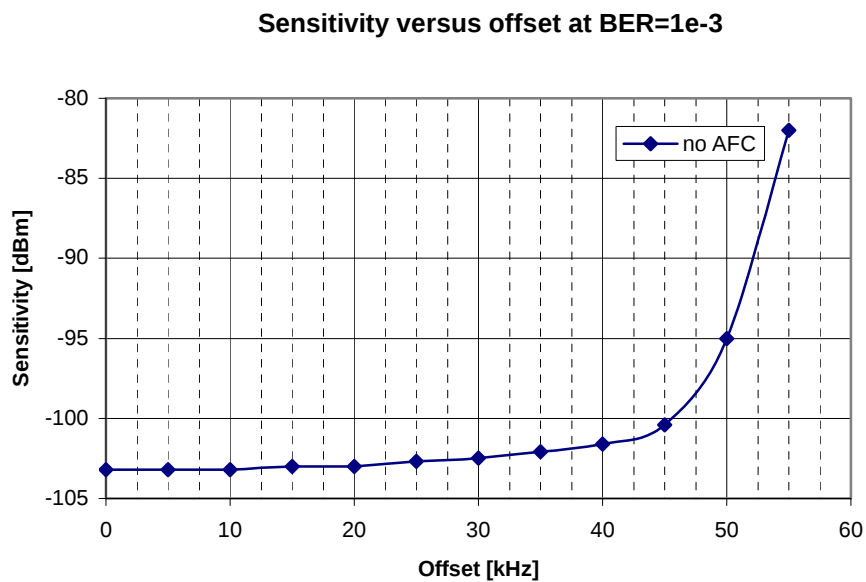
**BER Measurement Results**

| 1.134 kbps                                   | 2.4 kbps                                     | 4.8 kbps                                     | 9.6 kbps                                     | 19.2 kbps                                    | 38.4 kbps                                     | 57.6 kbps                                     | 115 kbps                                       |
|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|-----------------------------------------------|-----------------------------------------------|------------------------------------------------|
| BW=67 kHz<br>$\delta f_{FSK} \approx 30$ kHz | BW=67 kHz<br>$\delta f_{FSK} \approx 30$ kHz | BW=67 kHz<br>$\delta f_{FSK} \approx 30$ kHz | BW=67 kHz<br>$\delta f_{FSK} \approx 45$ kHz | BW=67 kHz<br>$\delta f_{FSK} \approx 45$ kHz | BW=134 kHz<br>$\delta f_{FSK} \approx 90$ kHz | BW=134 kHz<br>$\delta f_{FSK} \approx 90$ kHz | BW=200 kHz<br>$\delta f_{FSK} \approx 120$ kHz |

The table shows the optimal BW and  $\delta f_{FSK}$  selection for different data rates. Recommended only when using accurate crystal (20ppm or better).

**Frequency Offset Effecter Sensitivity Degradation**

BR=9.6 kbps, BER=10<sup>-3</sup>, BW=67 kHz,  $\delta f_{FSK}$  =60 kHz

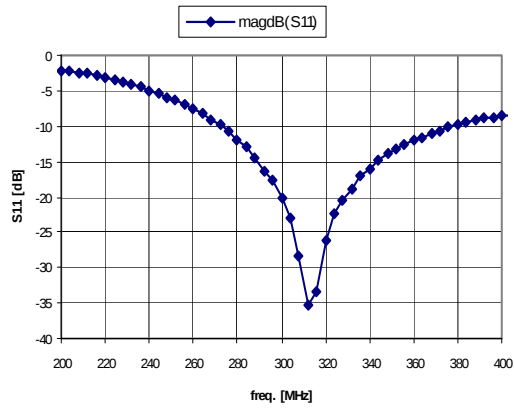


BR=9.6 kbps, BER=10<sup>-3</sup>, BW=134 kHz,  $\delta f_{FSK}$  =60 kHz

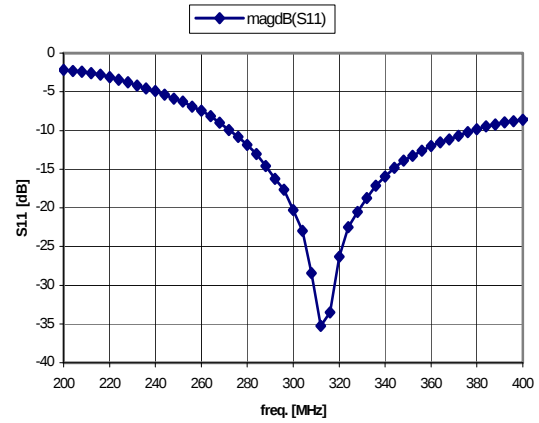
## Input impedance

Measured input return loss on the demo boards with suggested matching circuit

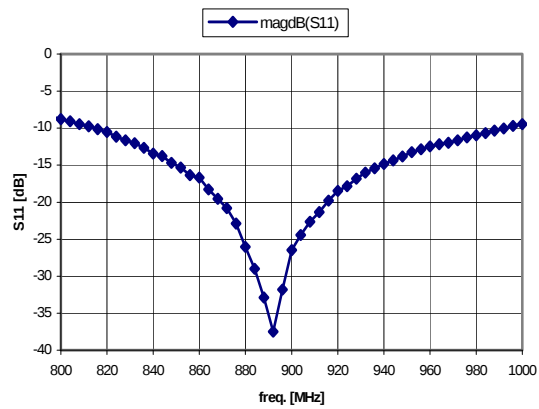
**315 MHz Matching to 50 Ohm**



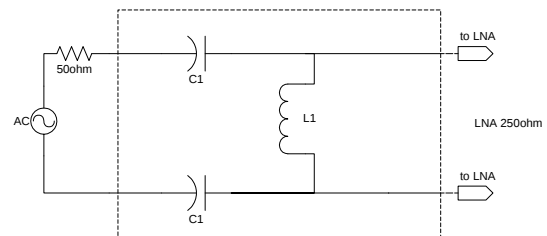
**433 MHz Matching to 50 Ohm**



**868 and 915 MHz Matching to 50 Ohm**



**Input Matching circuit**

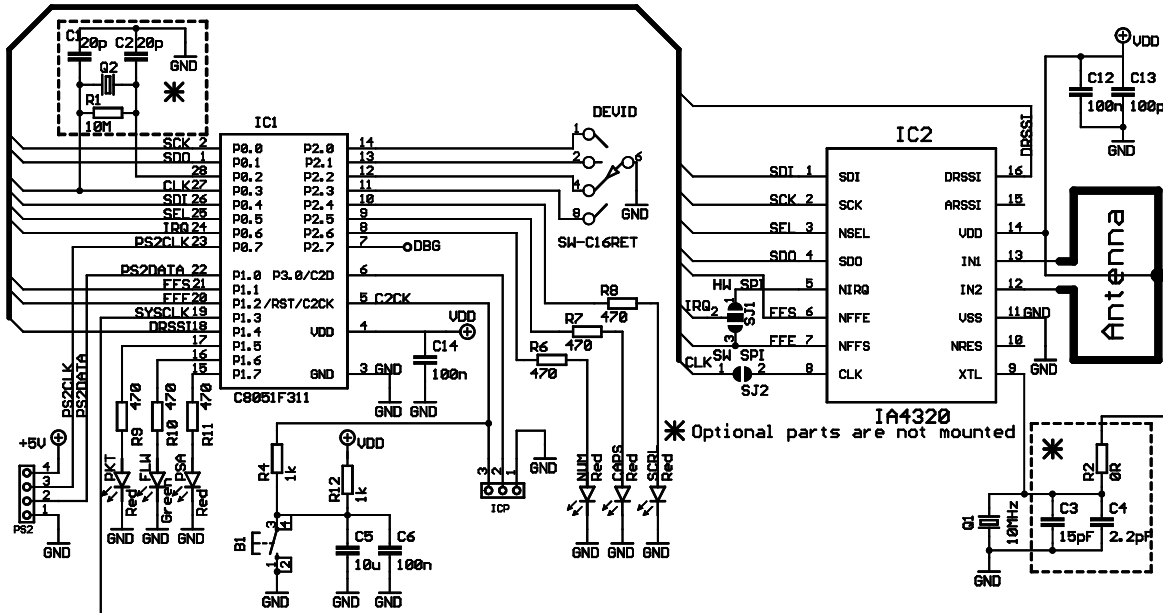


| Frequency [MHz] | L1 [nH] | C1 [pF] |
|-----------------|---------|---------|
| 915             | 15      | 3       |
| 868             | 15      | 3       |
| 433             | 36      | 7       |
| 315             | 56      | 9       |

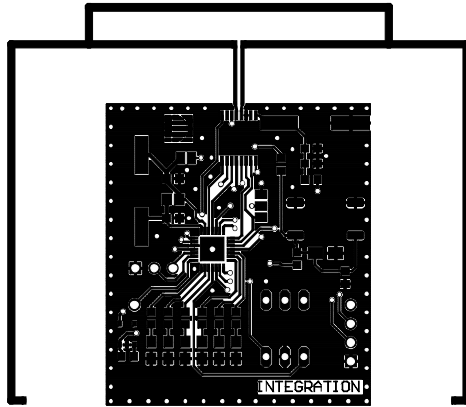
## EXAMPLE APPLICATIONS

### For Microcontroller Mode

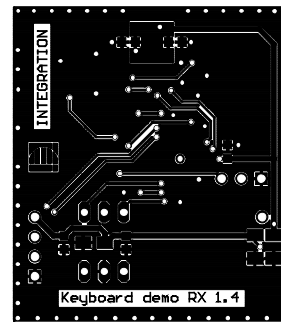
#### Schematic



PCB Layout of Wireless Keyboard Demo Receiver (operating in the 915 MHz band)



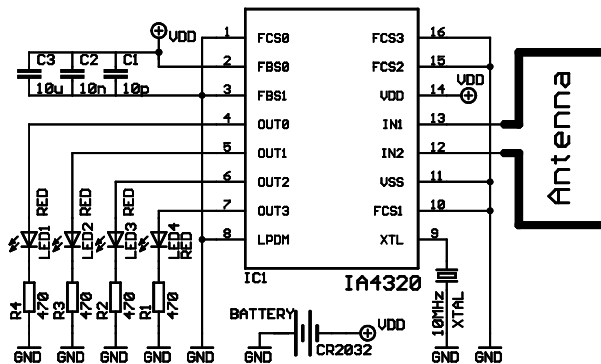
Top Layer



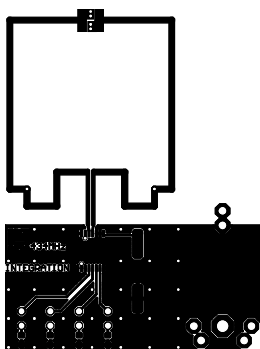
Bottom Layer

## Push-Button Demo Receiver (434 MHz)

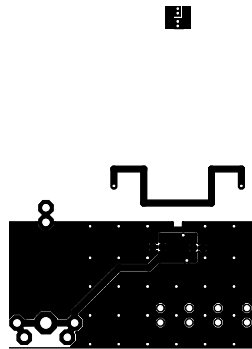
### Schematics



PCB Layout of Push-Button Receiver Demo Circuit (operating in the 434 MHz band)



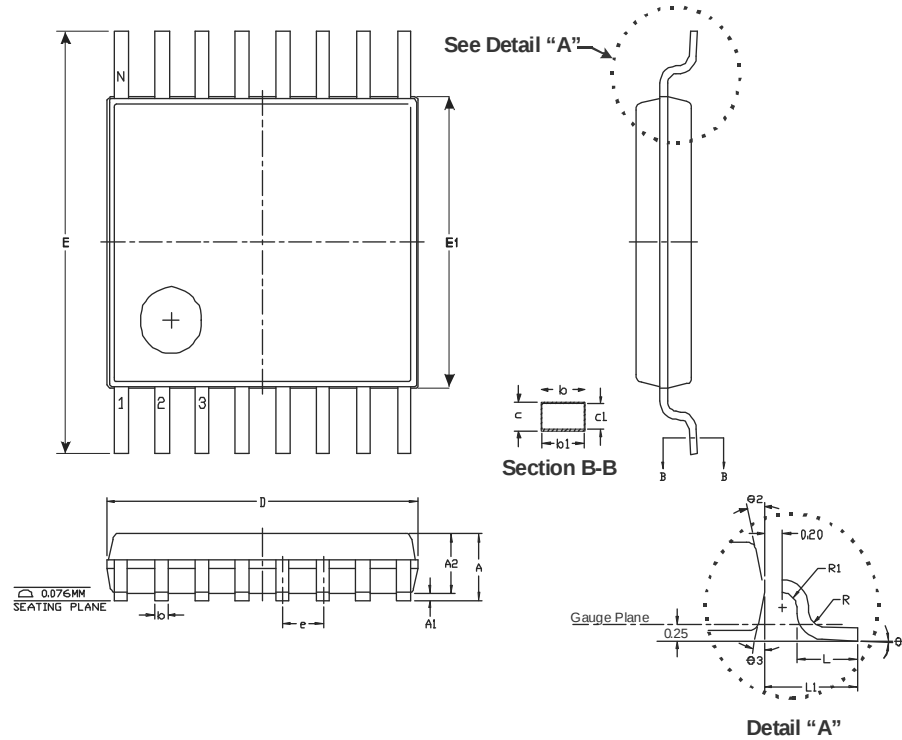
Top Layer



Bottom Layer

## PACKAGE INFORMATION

## 16-pin TSSOP



| Symbol | Dimensions in mm |      |      | Dimensions in Inches |       |       |
|--------|------------------|------|------|----------------------|-------|-------|
|        | Min.             | Nom. | Max. | Min.                 | Nom.  | Max.  |
| A      |                  |      | 1,20 |                      |       | 0,047 |
| A1     | 0,05             |      | 0,15 | 0,002                |       | 0,006 |
| A2     | 0,80             | 0,90 | 1,05 | 0,031                | 0,035 | 0,041 |
| b      | 0,19             |      | 0,30 | 0,007                |       | 0,012 |
| b1     | 0,19             | 0,22 | 0,25 | 0,007                | 0,009 | 0,010 |
| c      | 0,09             |      | 0,20 | 0,004                |       | 0,008 |
| c1     | 0,09             |      | 0,16 | 0,004                |       | 0,006 |
| D      | 4,90             | 5,00 | 5,10 | 0,193                | 0,197 | 0,201 |
| e      | 0.65 BSC.        |      |      | 0.026 BSC.           |       |       |
| E      | 6.40 BSC.        |      |      | 0.252 BSC.           |       |       |
| E1     | 4,30             | 4,40 | 4,50 | 0,169                | 0,173 | 0,177 |
| L      | 0,50             | 0,60 | 0,75 | 0,020                | 0,024 | 0,030 |
| L1     | 1.00 REF.        |      |      | 0.39 REF.            |       |       |
| R      | 0,09             |      |      | 0,004                |       |       |
| R1     | 0,09             |      |      | 0,004                |       |       |
| θ1     | 0                |      | 8    | 0                    |       | 8     |
| θ2     | 12 REF.          |      |      | 12 REF.              |       |       |
| θ3     | 12 REF.          |      |      | 12 REF.              |       |       |

## RELATED PRODUCTS AND DOCUMENTS

### Si4320 Universal ISM Band FSK Receiver

| DESCRIPTION         | ORDERING NUMBER       |
|---------------------|-----------------------|
| Si4320 16-pin TSSOP | Si4320-IC CC16 Rev J1 |
| die                 | see Silicon Labs      |

### Demo Boards and Development Kits

| DESCRIPTION                           | ORDERING NUMBER |
|---------------------------------------|-----------------|
| Development Kit                       | IA ISM – DK     |
| Remote Temperature Monitoring Station | IA ISM – DATD   |

### Related Resources

| DESCRIPTION                               | ORDERING NUMBER                                                                            |
|-------------------------------------------|--------------------------------------------------------------------------------------------|
| Antenna Selection Guide                   | IA ISM – AN1                                                                               |
| Antenna Development Guide                 | IA ISM – AN2                                                                               |
| Si4220 Universal ISM Band FSK Transmitter | See <a href="http://www.silabs.com/integration">www.silabs.com/integration</a> for details |

**Note:** Volume orders must include chip revision to be accepted.

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