Si4430/31/32-B1

Si4430/31/32 ISM TRANSCEIVER

Features

- Frequency Range
  - 240–930 MHz (Si4431/32)
  - 900–960 MHz (Si4430)
- Sensitivity = –121 dBm
- Output power range
  - +20 dBm Max (Si4432)
  - +13 dBm Max (Si4430/31)
- Low Power Consumption
  - 18.5 mA receive
  - 30 mA @ +13 dBm transmit
  - 85 mA @ +20 dBm transmit
- Data Rate = 0.123 to 256 kbps
- FSK, GFSK, and OOK modulation
- Power Supply = 1.8 to 3.6 V
- Ultra low power shutdown mode
- Digital RSSI
- Wake-up timer
- Auto-frequency calibration (AFC)
- Power-on-reset (POR)
- Antenna diversity and TR switch control
- Configurable packet handler
- Preamble detector
- TX and RX 64 byte FIFOs
- Low battery detector
- Temperature sensor and 8-bit ADC
- –40 to +85 °C temperature range
- Integrated voltage regulators
- Frequency hopping capability
- On-chip crystal tuning
- 20-Pin QFN package
- Low BOM

Applications

- Remote control
- Home security & alarm
- Telemetry
- Personal data logging
- Toy control
- Tire pressure monitoring
- Wireless PC peripherals
- Remote meter reading
- Remote keyless entry
- Home automation
- Industrial control
- Sensor networks
- Health monitors
- Tag readers

Description

Silicon Laboratories' Si4430/31/32 devices are highly integrated, single chip wireless ISM transceivers. The high-performance EZRadioPRO® family includes a complete line of transmitters, receivers, and transceivers allowing the RF system designer to choose the optimal wireless part for their application.

The Si4430/31/32's high level of integration offers reduced BOM cost while simplifying the overall system design. The extremely low receive sensitivity (–121 dBm) coupled with industry leading +20 dBm output power ensures extended range and improved link performance. Built-in antenna diversity and support for frequency hopping can be used to further extend range and enhance performance.

The Si4430/31/32 offers advanced radio features including continuous frequency coverage from 240–960 MHz in 156 Hz or 312 Hz steps allowing precise tuning control. Additional system features such as an automatic wake-up timer, low battery detector, 64 byte TX/RX FIFOs, automatic packet handling, and preamble detection reduce overall current consumption and allow the use of lower-cost system MCUs. An integrated temperature sensor, general purpose ADC, power-on-reset (POR), and GPIOs further reduce overall system cost and size.

The Si4430/31/32's digital receive architecture features a high-performance ADC and DSP based modem which performs demodulation, filtering, and packet handling for increased flexibility and performance. The direct digital transmit modulation and automatic PA power ramping ensure precise transmit modulation and reduced spectral spreading ensuring compliance with global regulations including FCC, ETSI, ARIB, and 802.15.4d regulations.

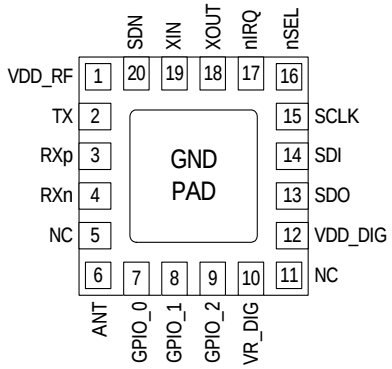
An easy-to-use calculator is provided to quickly configure the radio settings, simplifying customer's system design and reducing time to market.

Ordering Information:

See page 67.

Pin Assignments

Si4430/31/32



Patents pending

Functional Block Diagram

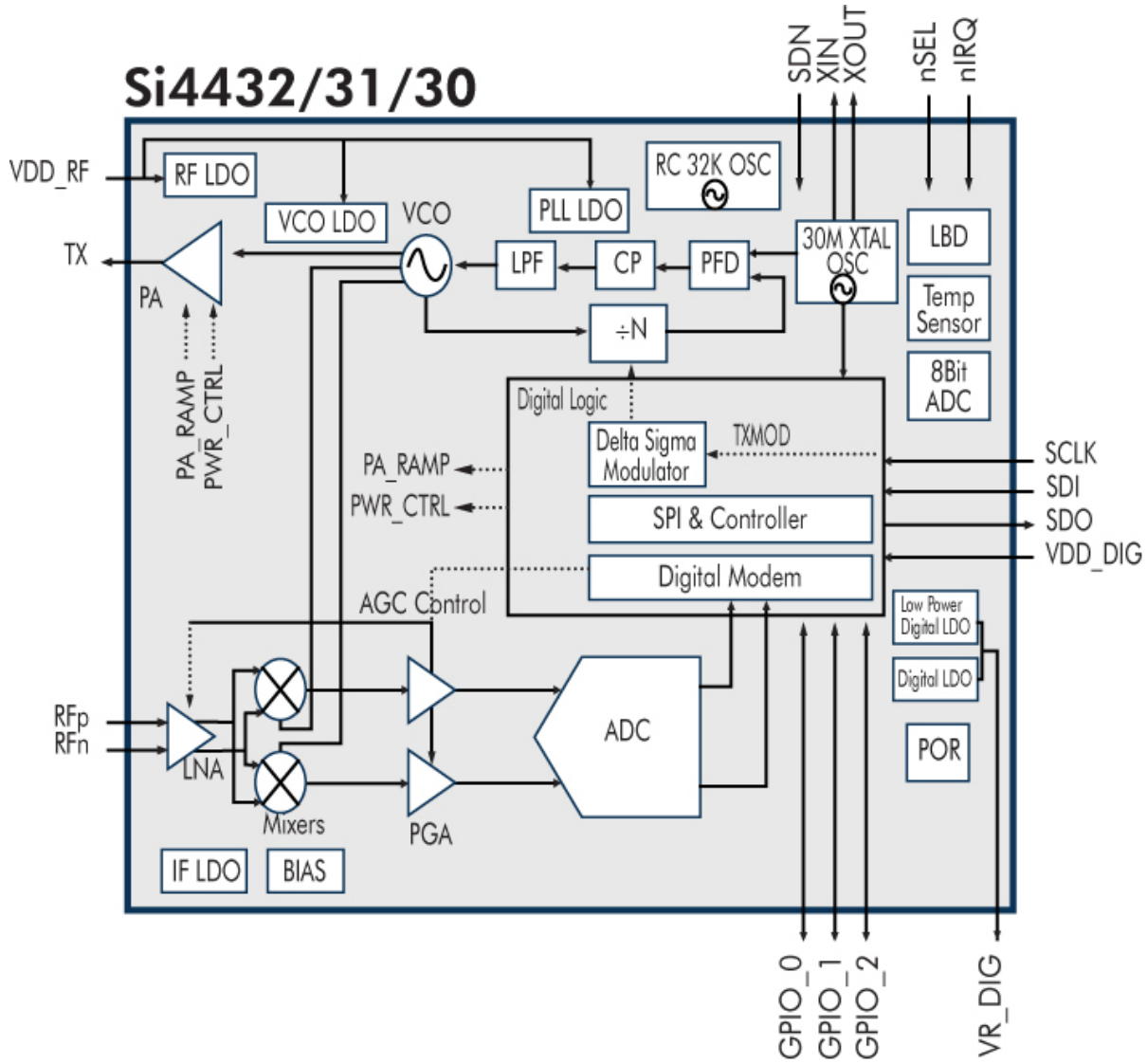


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Table 1. DC Characteristics[1]

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Supply Voltage Range	V_{DD}		1.8	3.0	3.6	V
Power Saving Modes	$I_{Shutdown}$	RC Oscillator, Main Digital Regulator, and Low Power Digital Regulator OFF[2]	—	15	50	nA
	$I_{Standby}$	Low Power Digital Regulator ON (Register values retained) and Main Digital Regulator, and RC Oscillator OFF	—	450	800	nA
	I_{Sleep}	RC Oscillator and Low Power Digital Regulator ON (Register values retained) and Main Digital Regulator OFF	—	1	—	µA
	$I_{Sensor-LBD}$	Main Digital Regulator and Low Battery Detector ON, Crystal Oscillator and all other blocks OFF[2]	—	1	—	µA
	$I_{Sensor-TS}$	Main Digital Regulator and Temperature Sensor ON, Crystal Oscillator and all other blocks OFF[2]	—	1	—	µA
	I_{Ready}	Crystal Oscillator and Main Digital Regulator ON, all other blocks OFF. Crystal Oscillator buffer disabled	—	800	—	µA
TUNE Mode Current	I_{Tune}	Synthesizer and regulators enabled	—	8.5	—	mA
RX Mode Current	I_{RX}		—	18.5	—	mA
TX Mode Current —Si4432	I_{TX_+20}	txpow[2:0] = 111 (+20 dBm) Using Silicon Labs' Reference Design. TX current consumption is dependent on match and board layout.	—	85	—	mA
TX Mode Current —Si4430/31	I_{TX_+13}	txpow[2:0] = 110 (+13 dBm) Using Silicon Labs' Reference Design. TX current consumption is dependent on match and board layout.	—	30	—	mA
	I_{TX_+1}	txpow[2:0] = 010 (+1 dBm) Using Silicon Labs' Reference Design. TX current consumption is dependent on match and board layout.	—	17	—	mA

Notes:
1. All specification guaranteed by production test unless otherwise noted. Production test conditions and max limits are listed in the "Production Test Conditions" section on page 14.
2. Guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.

Table 2. Synthesizer AC Electrical Characteristics[1]

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Synthesizer Frequency Range—Si4431/32	F_{SYN}		240	—	930	MHz
Synthesizer Frequency Range—Si4430	F_{SYN}		900	—	960	MHz
Synthesizer Frequency Resolution[2]	F_{RES-LB}	Low Band, 240–480 MHz	—	156.25	—	Hz
	F_{RES-HB}	High Band, 480–960 MHz	—	312.5	—	Hz
Reference Frequency Input Level[2]	f_{REF_LV}	When using external reference signal driving XOUT pin, instead of using crystal. Measured peak-to-peak (V_{PP})	0.7	—	1.6	V
Synthesizer Settling Time[2]	t_{LOCK}	Measured from exiting Ready mode with XOSC running to any frequency. Including VCO Calibration.	—	200	—	µs
Residual FM[2]	ΔF_{RMS}	Integrated over ±250 kHz bandwidth (500 Hz lower bound of integration)	—	2	4	kHz_{RMS}
Phase Noise[2]	$L\phi(f_M)$	ΔF = 10 kHz	—	–80	—	dBc/Hz
		ΔF = 100 kHz	—	–90	—	dBc/Hz
		ΔF = 1 MHz	—	–115	—	dBc/Hz
		ΔF = 10 MHz	—	–130	—	dBc/Hz

Notes:
1. All specification guaranteed by production test unless otherwise noted. Production test conditions and max limits are listed in the "Production Test Conditions" section on page 14.
2. Guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.

Table 3. Receiver AC Electrical Characteristics[1]

Parameter	Symbol	Conditions	Min	Typ	Max	Units
RX Frequency Range—Si4431/32	F_{RX}		240	—	930	MHz
RX Frequency Range—Si4430	F_{RX}		900	—	960	MHz
RX Sensitivity[2]	P_{RX_2}	(BER < 0.1%) (2 kbps, GFSK, BT = 0.5, Δf = ±5 kHz)[3]	—	–121	—	dBm
	P_{RX_40}	(BER < 0.1%) (40 kbps, GFSK, BT = 0.5, Δf = ±20 kHz)[3]	—	–108	—	dBm
	P_{RX_100}	(BER < 0.1%) (100 kbps, GFSK, BT = 0.5, Δf = ±50 kHz)[3]	—	–104	—	dBm
	P_{RX_125}	(BER < 0.1%) (125 kbps, GFSK, BT = 0.5, Δf = ±62.5 kHz)	—	–101	—	dBm
	P_{RX_OOK}	(BER < 0.1%) (4.8 kbps, 350 kHz BW, OOK)[3]	—	–110	—	dBm
		(BER < 0.1%) (40 kbps, 400 kHz BW, OOK)[3]	—	–102	—	dBm
RX Channel Bandwidth[3]	BW		2.6	—	620	kHz
BER Variation vs Power Level[3]	P_{RX_RES}	Up to +5 dBm Input Level	—	0	0.1	ppm
LNA Input Impedance[3] (Unmatched—measured differentially across RX input pins)	R_{IN-RX}	915 MHz	—	51–60j	—	Ω
		868 MHz	—	54–63j	—	
		433 MHz	—	89–110j	—	
		315 MHz	—	107–137j	—	
RSSI Resolution	RES_{RSSI}		—	±0.5	—	dB
±1-Ch Offset Selectivity[3]	C/I_{1-CH}	Desired Ref Signal 3 dB above sensitivity, BER < 0.1%. Interferer and desired modulated with 40 kbps ΔF = 20 kHz GFSK with BT = 0.5, channel spacing = 150 kHz	—	–31	—	dB
±2-Ch Offset Selectivity[3]	C/I_{2-CH}		—	–35	—	dB
≥ ±3-Ch Offset Selectivity[3]	C/I_{3-CH}		—	–40	—	dB
Blocking at 1 MHz Offset[3]	$1M_{BLOCK}$	Desired Ref Signal 3 dB above sensitivity. Interferer and desired modulated with 40 kbps ΔF = 20 kHz GFSK with BT = 0.5	—	–52	—	dB
Blocking at 4 MHz Offset[3]	$4M_{BLOCK}$		—	–56	—	dB
Blocking at 8 MHz Offset[3]	$8M_{BLOCK}$		—	–63	—	dB
Image Rejection[3]	Im_{REJ}	Rejection at the image frequency. IF=937 kHz	—	–30	—	dB
Spurious Emissions[3]	P_{OB_RX1}	Measured at RX pins	—	—	–54	dBm

Notes:

1. All specification guaranteed by production test unless otherwise noted. Production test conditions and max limits are listed in the "Production Test Conditions" section on page 14.
2. Receive sensitivity at multiples of 30 MHz may be degraded. If channels with a multiple of 30 MHz are required it is recommended to shift the crystal frequency. Contact Silicon Labs Applications Support for recommendations.
3. Guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.

Table 4. Transmitter AC Electrical Characteristics[1]

Parameter	Symbol	Conditions	Min	Typ	Max	Units
TX Frequency Range—Si4431/32	F_{TX}		240	—	930	MHz
TX Frequency Range—Si4430	F_{TX}		900	—	960	MHz
FSK Data Rate[2]	DR_{FSK}		0.123	—	256	kbps
OOK Data Rate[2]	DR_{OOK}		0.123	—	40	kbps
Modulation Deviation	Δf1	860–960 MHz	±0.625		±320	kHz
	Δf2	240–860 MHz	±0.625		±160	kHz
Modulation Deviation Resolution[2]	Δf_{RES}		—	0.625	—	kHz
Output Power Range—Si4432[3]	P_{TX}		+1	—	+20	dBm
Output Power Range—Si4430/31[3]	P_{TX}		–8	—	+13	dBm
TX RF Output Steps[2]	ΔP_{RF_OUT}	controlled by txpow[2:0]	—	3	—	dB
TX RF Output Level[2] Variation vs. Temperature	ΔP_{RF_TEMP}	–40 to +85 °C	—	2	—	dB
TX RF Output Level Variation vs. Frequency[2]	ΔP_{RF_FREQ}	Measured across any one frequency band	—	1	—	dB
Transmit Modulation Filtering[2]	B*T	Gaussian Filtering Bandwith Time Product	—	0.5	—	
Spurious Emissions[2]	$P_{OB\text{-}TX1}$	P_{OUT} = +13 dBm, Frequencies <1 GHz	—	—	–54	dBm
	$P_{OB\text{-}TX2}$	1–12.75 GHz, excluding harmonics	—	—	–54	dBm
Harmonics[2]	P_{2HARM}	Using reference design TX matching network and filter with max output power. Harmonics reduce linearly with output power.	—	—	–42	dBm
	P_{3HARM}		—	—	–42	dBm

Notes:
1. All specification guaranteed by production test unless otherwise noted. Production test conditions and max limits are listed in the "Production Test Conditions" section on page 14.
2. Guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.
3. Output power is dependent on matching components, board layout, and is measured at the pin.

Table 5. Auxiliary Block Specifications[1]

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Temperature Sensor Accuracy[2]	TS_A	After calibrated via sensor offset register tvoffs[7:0]	—	0.5	—	°C
Temperature Sensor Sensitivity[2]	TS_S		—	5	—	mV/°C
Low Battery Detector Resolution[2]	LBD_{RES}		—	50	—	mV
Low Battery Detector Conversion Time[2]	LBD_{CT}		—	250	—	µs
Microcontroller Clock Output Frequency	F_{MC}	Configurable to 30 MHz, 15 MHz, 10 MHz, 4 MHz, 3 MHz, 2 MHz, 1 MHz, or 32.768 kHz	32.768K	—	30M	Hz
General Purpose ADC Resolution[2]	ADC_{ENB}		—	8	—	bit
General Purpose ADC Bit Resolution[2]	ADC_{RES}		—	4	—	mV/bit
Temp Sensor & General Purpose ADC Conversion Time[2]	ADC_{CT}		—	305	—	µs
30 MHz XTAL Start-Up time	t_{30M}	Using XTAL and board layout in reference design. Start-up time will vary with XTAL type and board layout.	—	600	—	µs
30 MHz XTAL Cap Resolution[2]	$30M_{RES}$	See "5.8. Crystal Oscillator" on page 40 for total load capacitance calculation	—	97	—	fF
32 kHz XTAL Start-Up Time[2]	t_{32k}		—	6	—	sec
32 kHz Accuracy using Internal RC Oscillator[2]	$32KRC_{RES}$		—	1000	—	ppm
32 kHz RC Oscillator Start-Up	t_{32kRC}		—	500	—	µs
POR Reset Time	t_{POR}		—	16	—	ms
Software Reset Time[2]	t_{soft}		—	250	—	µs

Notes:

1. All specification guaranteed by production test unless otherwise noted. Production test conditions and max limits are listed in the "Production Test Conditions" section on page 14.
2. Guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.

Table 6. Digital IO Specifications (SDO, SDI, SCLK, nSEL, and nIRQ)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Rise Time	T_{RISE}	0.1 x V_{DD} to 0.9 x V_{DD}, C_L= 5 pF	—	—	8	ns
Fall Time	T_{FALL}	0.9 x V_{DD} to 0.1 x V_{DD}, C_L= 5 pF	—	—	8	ns
Input Capacitance	C_{IN}		—	—	1	pF
Logic High Level Input Voltage	V_{IH}		V_{DD} – 0.6	—	—	V
Logic Low Level Input Voltage	V_{IL}			—	0.6	V
Input Current	I_{IN}	0<V_{IN}< V_{DD}	–100	—	100	nA
Logic High Level Output Voltage	V_{OH}	I_{OH}<1 mA source, V_{DD}=1.8 V	V_{DD} – 0.6	—	—	V
Logic Low Level Output Voltage	V_{OL}	I_{OL}<1 mA sink, V_{DD}=1.8 V	—	—	0.6	V

Note: All specifications guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.

Table 7. GPIO Specifications (GPIO_0, GPIO_1, and GPIO_2)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Rise Time	T_{RISE}	0.1 x V_{DD} to 0.9 x V_{DD}, C_L= 10 pF, DRV<1:0>=HH	—	—	8	ns
Fall Time	T_{FALL}	0.9 x V_{DD} to 0.1 x V_{DD}, C_L= 10 pF, DRV<1:0>=HH	—	—	8	ns
Input Capacitance	C_{IN}		—	—	1	pF
Logic High Level Input Voltage	V_{IH}		V_{DD} – 0.6	—		V
Logic Low Level Input Voltage	V_{IL}		—	—	0.6	V
Input Current	I_{IN}	0<V_{IN}< V_{DD}	–100	—	100	nA
Input Current If Pullup is Activated	I_{INP}	V_{IL}=0 V	5	—	25	µA
Maximum Output Current	I_{OmaxLL}	DRV<1:0>=LL	0.1	0.5	0.8	mA
	I_{OmaxLH}	DRV<1:0>=LH	0.9	2.3	3.5	mA
	I_{OmaxHL}	DRV<1:0>=HL	1.5	3.1	4.8	mA
	I_{OmaxHH}	DRV<1:0>=HH	1.8	3.6	5.4	mA
Logic High Level Output Voltage	V_{OH}	I_{OH}< I_{Omax} source, V_{DD}=1.8 V	V_{DD} – 0.6	—	—	V
Logic Low Level Output Voltage	V_{OL}	I_{OL}< I_{Omax} sink, V_{DD}=1.8 V	—	—	0.6	V

Note: All specifications guaranteed by qualification. Qualification test conditions are listed in the "Production Test Conditions" section on page 14.

Table 8. Absolute Maximum Ratings

Parameter	Value	Unit
V_{DD} to GND	–0.3, +3.6	V
Instantaneous $V_{RF\text{-}peak}$ to GND on TX Output Pin	–0.3, +8.0	V
Sustained $V_{RF\text{-}peak}$ to GND on TX Output Pin	–0.3, +6.5	V
Voltage on Digital Control Inputs	–0.3, V_{DD} + 0.3	V
Voltage on Analog Inputs	–0.3, V_{DD} + 0.3	V
RX Input Power	+10	dBm
Operating Ambient Temperature Range T_A	–40 to +85	°C
Thermal Impedance θ_{JA}	30	°C/W
Junction Temperature T_J	+125	°C
Storage Temperature Range T_{STG}	–55 to +125	°C

Note: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at or beyond these ratings in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. Power Amplifier may be damaged if switched on without proper load or termination connected. TX matching network design will influence TX $V_{RF\text{-}peak}$ on TX output pin. Caution: ESD sensitive device.

1.1. Definition of Test Conditions

Production Test Conditions:

- T_A = +25 °C
- V_{DD} = +3.3 VDC
- Sensitivity measured at 919 MHz
- TX output power measured at 915 MHz
- External reference signal (XOUT) = 1.0 V_{PP} at 30 MHz, centered around 0.8 VDC
- Production test schematic (unless noted otherwise)
- All RF input and output levels referred to the pins of the Si4430/31/32 (not the RF module)

Qualification Test Conditions:

- T_A = –40 to +85 °C
- V_{DD} = +1.8 to +3.6 VDC
- Using TX/RX Split Antenna reference design or production test schematic
- All RF input and output levels referred to the pins of the Si4430/31/32 (not the RF module)

2. Functional Description

The Si4430/31/32 are ISM wireless transceivers with continuous frequency tuning over their specified bands which encompasses from 240–960 MHz. The wide operating voltage range of 1.8–3.6 V and low current consumption makes the Si4430/31/32 an ideal solution for battery powered applications.

The Si4430/31/32 operates as a time division duplexing (TDD) transceiver where the device alternately transmits and receives data packets. The device uses a single-conversion mixer to downconvert the 2-level FSK/GFSK/OOK modulated receive signal to a low IF frequency. Following a programmable gain amplifier (PGA) the signal is converted to the digital domain by a high performance ΔΣ ADC allowing filtering, demodulation, slicing, and packet handling to be performed in the built-in DSP increasing the receiver's performance and flexibility versus analog based architectures. The demodulated signal is then output to the system MCU through a programmable GPIO or via the standard SPI bus by reading the 64-byte RX FIFO.

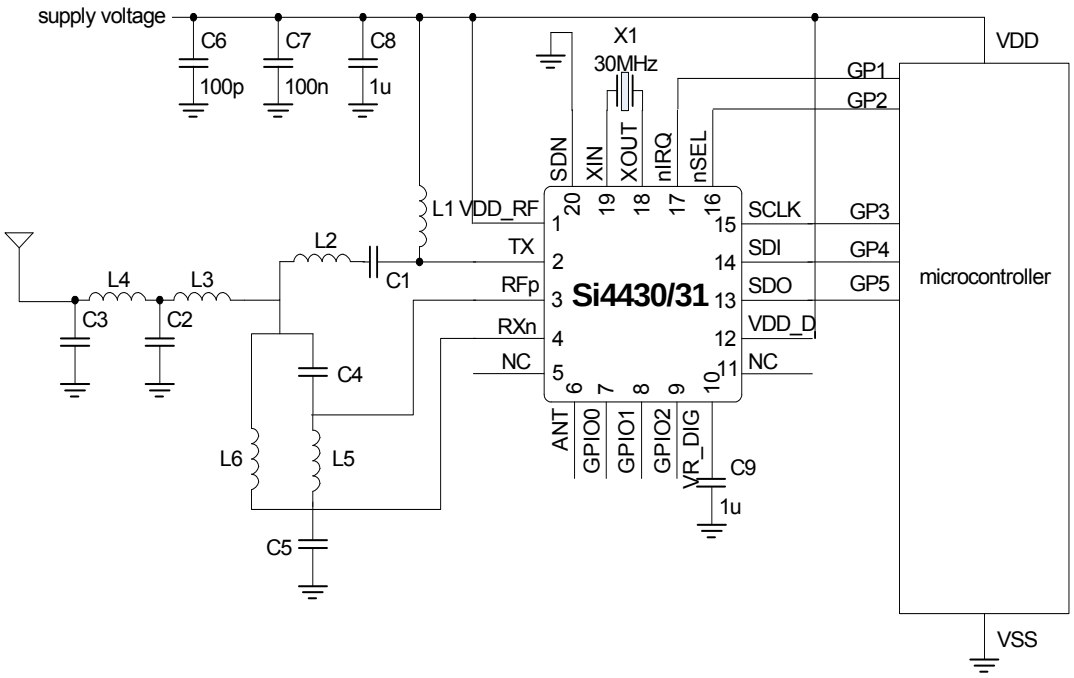
A single high precision local oscillator (LO) is used for both transmit and receive modes since the transmitter and receiver do not operate at the same time. The LO is generated by an integrated VCO and ΔΣ Fractional-N PLL synthesizer. The synthesizer is designed to support configurable data rates, output frequency and frequency deviation at any frequency between 240–960 MHz. The transmit FSK data is modulated directly into the ΔΣ data stream and can be shaped by a Gaussian low-pass filter to reduce unwanted spectral content.

The Si4432's PA output power can be configured between +1 and +20 dBm in 3 dB steps, while the Si4430/31's PA output power can be configured between –8 and +13 dBm in 3 dB steps. The PA is single-ended to allow for easy antenna matching and low BOM cost. The PA incorporates automatic ramp-up and rampdown control to reduce unwanted spectral spreading. The +20 dBm power amplifier of the Si4432 can also be used to compensate for the reduced performance of a lower cost, lower performance antenna or antenna with size constraints due to a small form-factor. Competing solutions require large and expensive external PAs to achieve comparable performance. The Si4430/31/32 supports frequency hopping, TX/RX switch control, and antenna diversity switch control to extend the link range and improve performance.

The Si4430/31/32 is designed to work with a microcontroller, crystal, and a few external components to create a very low cost system as shown Figure 1. Voltage regulators are integrated on-chip which allows for a wide operating supply voltage range from +1.8 to +3.6 V. A standard 4-pin SPI bus is used to communicate with an external microcontroller. Three configurable general purpose I/Os are available. A complete list of the available GPIO functions is shown in "8. Auxiliary Functions" on page 50 and includes microcontroller clock output, Antenna Diversity, POR, and various interrupts.

The application shown in Figure 1 is designed for a system with a TX/RX direct-tie configuration without the use of a TX/RX switch. Most lower power applications will use this configuration. A complete direct-tie reference design is available from Silicon Laboratories applications support.

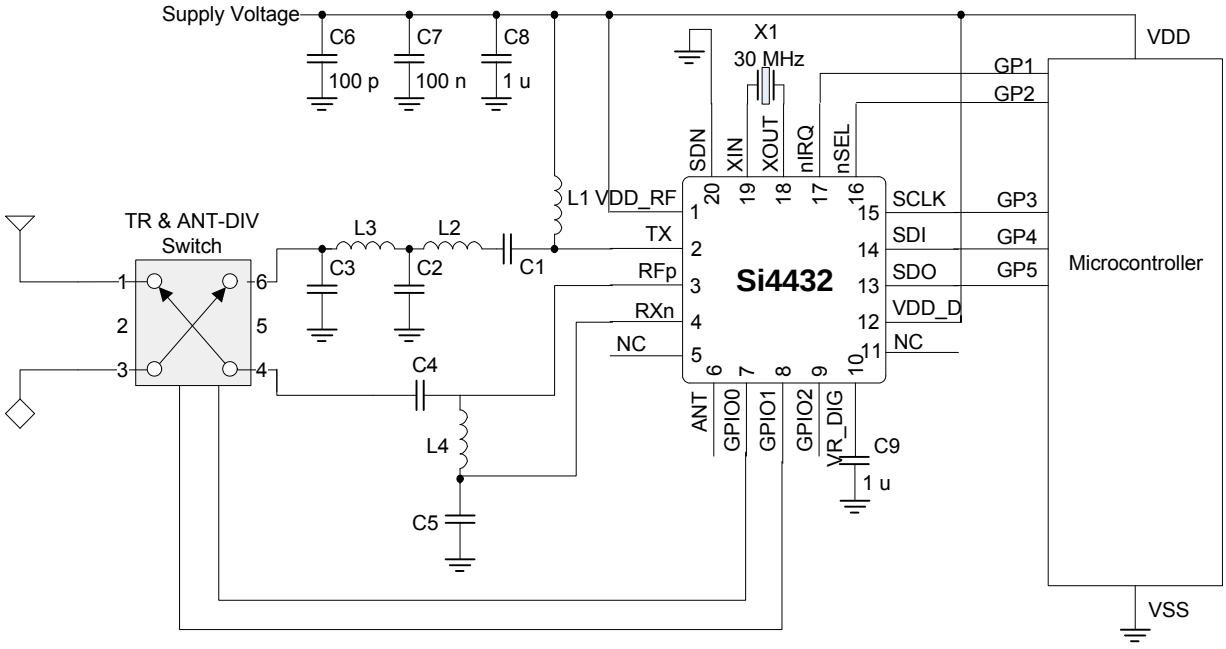
For applications seeking improved performance in the presence of multipath fading antenna diversity can be used. Antenna diversity support is integrated into the Si4430/31/32 and can improve the system link budget by 8–10 dB in the presence of these fading conditions, resulting in substantial range increases. A complete Antenna Diversity reference design is available from Silicon Laboratories applications support.



Programmable load capacitors for X1 are integrated.

L1-L6 and C1-C5 values depend on frequency band, antenna impedance, output power and supply voltage range.

Figure 1. Si4430/31 RX/TX Direct-Tie Application Example



Programmable load capacitors for X1 are integrated.

L1–L4 and C1–C5 values depend on frequency band, antenna impedance, output power, and supply voltage range.

Figure 2. Si4432 Antenna Diversity Application Example

2.1. Operating Modes

The Si4430/31/32 provides several operating modes which can be used to optimize the power consumption for a given application. Depending upon the system communication protocol, an optimal trade-off between the radio wake time and power consumption can be achieved.

Table 9 summarizes the operating modes of the Si4430/31/32. In general, any given operating mode may be classified as an active mode or a power saving mode. The table indicates which block(s) are enabled (active) in each corresponding mode. With the exception of the SHUTDOWN mode, all can be dynamically selected by sending the appropriate commands over the SPI. An “X” in any cell means that, in the given mode of operation, that block can be independently programmed to be either ON or OFF, without noticeably impacting the current consumption. The SPI circuit block includes the SPI interface hardware and the device register space. The 32 kHz OSC block includes the 32.768 kHz RC oscillator or 32.768 kHz crystal oscillator and wake-up timer. AUX (Auxiliary Blocks) includes the temperature sensor, general purpose ADC, and low-battery detector.

Table 9. Operating Modes

Mode Name	Circuit Blocks								
	Digital LDO	SPI	32 kHz OSC	AUX	30 MHz XTAL	PLL	PA	RX	I_{VDD}
SHUT-DOWN	OFF (Register contents lost)	OFF	OFF	OFF	OFF	OFF	OFF	OFF	15 nA
STANDBY	ON (Register contents retained)	ON	OFF	OFF	OFF	OFF	OFF	OFF	450 nA
SLEEP		ON	ON	X	OFF	OFF	OFF	OFF	1 µA
SENSOR		ON	X	ON	OFF	OFF	OFF	OFF	1 µA
READY		ON	X	X	ON	OFF	OFF	OFF	800 µA
TUNING		ON	X	X	ON	ON	OFF	OFF	8.5 mA
TRANSMIT		ON	X	X	ON	ON	ON	OFF	30 mA*
RECEIVE		ON	X	X	ON	ON	OFF	ON	18.5 mA

***Note:** Using Si4430/31 at +13 dBm using recommended reference design.

3. Controller Interface

3.1. Serial Peripheral Interface (SPI)

The Si4430/31/32 communicates with the host MCU over a standard 3-wire SPI interface: SCLK, SDI, and nSEL. The host MCU can read data from the device on the SDO output pin. A SPI transaction is a 16-bit sequence which consists of a Read-Write ($\overline{R}$/W) select bit, followed by a 7-bit address field (ADDR), and an 8-bit data field (DATA) as demonstrated in Figure 3. The 7-bit address field is used to select one of the 128, 8-bit control registers. The $\overline{R}$/W select bit determines whether the SPI transaction is a read or write transaction. If $\overline{R}$/W = 1 it signifies a WRITE transaction, while $\overline{R}$/W = 0 signifies a READ transaction. The contents (ADDR or DATA) are latched into the Si4430/31/32 every eight clock cycles. The timing parameters for the SPI interface are shown in Table 10. The SCLK rate is flexible with a maximum rate of 10 MHz.

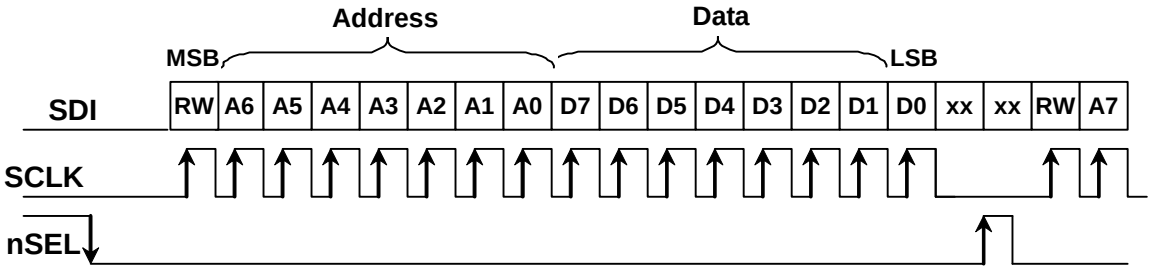
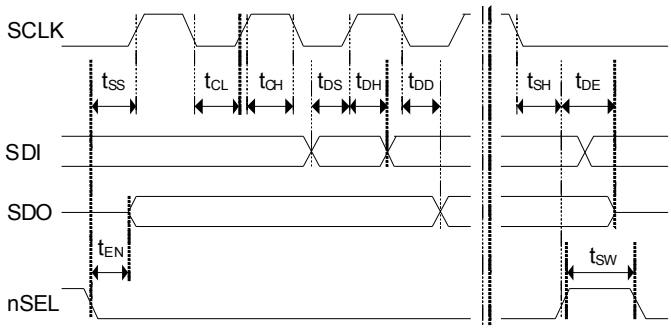


Figure 3. SPI Timing

Table 10. Serial Interface Timing Parameters

Symbol	Parameter	Min (nsec)	Diagram
t_{CH}	Clock high time	40	
t_{CL}	Clock low time	40	
t_{DS}	Data setup time	20	
t_{DH}	Data hold time	20	
t_{DD}	Output data delay time	20	
t_{EN}	Output enable time	20	
t_{DE}	Output disable time	50	
t_{SS}	Select setup time	20	
t_{SH}	Select hold time	50	
t_{SW}	Select high period	80	

To read back data from the Si4430/31/32, the R/W bit must be set to 0 followed by the 7-bit address of the register from which to read. The 8 bit DATA field following the 7-bit ADDR field is ignored on the SDI pin when R/W = 0. The next eight negative edge transitions of the SCLK signal will clock out the contents of the selected register. The data read from the selected register will be available on the SDO output pin. The READ function is shown in Figure 4. After the READ function is completed the SDO pin will remain at either a logic 1 or logic 0 state depending on the last data bit clocked out (D0). When nSEL goes high the SDO output pin will be pulled high by internal pullup.

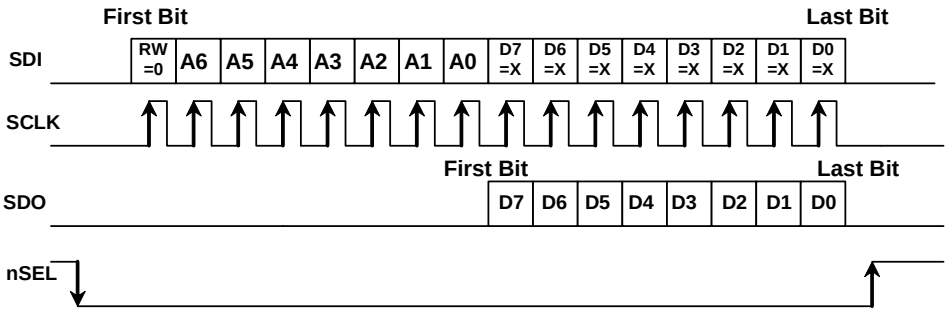


Figure 4. SPI Timing—READ Mode

The SPI interface contains a burst read/write mode which allows for reading/writing sequential registers without having to re-send the SPI address. When the nSEL bit is held low while continuing to send SCLK pulses, the SPI interface will automatically increment the ADDR and read from/write to the next address. An example burst write transaction is illustrated in Figure 5 and a burst read in Figure 6. As long as nSEL is held low, input data will be latched into the Si4430/31/32 every eight SCLK cycles.

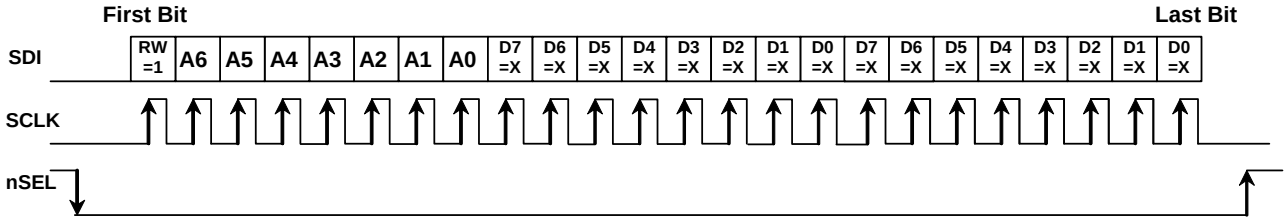


Figure 5. SPI Timing—Burst Write Mode

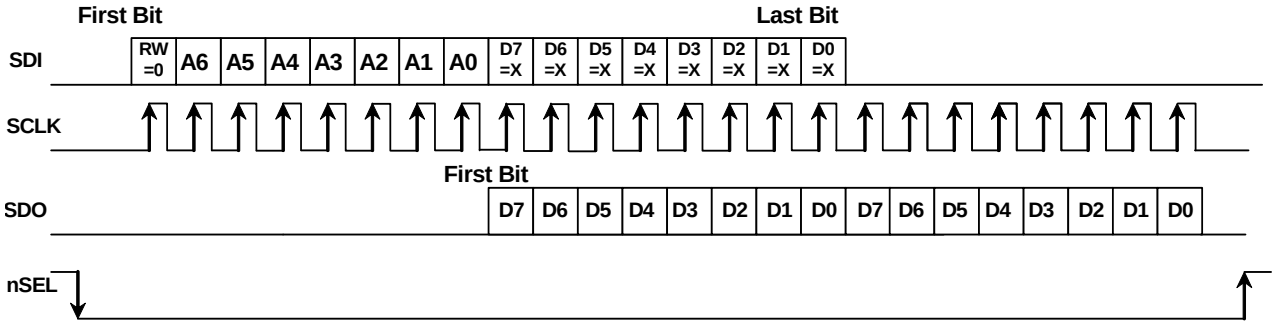


Figure 6. SPI Timing—Burst Read Mode

3.2. Operating Mode Control

There are four primary states in the Si4430/31/32 radio state machine: SHUTDOWN, IDLE, TX, and RX (see Figure 7). The SHUTDOWN state completely shuts down the radio to minimize current consumption. There are five different configurations/options for the IDLE state which can be selected to optimize the chip to the applications needs. "Register 07h. Operating Mode and Function Control 1" controls which operating mode/state is selected with the exception of SHUTDOWN which is controlled by SDN pin 20. The TX and RX state may be reached automatically from any of the IDLE states by setting the txon/rxon bits in "Register 07h. Operating Mode and Function Control 1". Table 11 shows each of the operating modes with the time required to reach either RX or TX mode as well as the current consumption of each mode.

The Si4430/31/32 includes a low-power digital regulated supply (LPLDO) which is internally connected in parallel to the output of the main digital regulator (and is available externally at the VR_DIG pin). This common digital supply voltage is connected to all digital circuit blocks including the digital modem, crystal oscillator, SPI, and register space. The LPLDO has extremely low quiescent current consumption but limited current supply capability; it is used only in the IDLE-STANDBY and IDLE-SLEEP modes. The main digital regulator is automatically enabled in all other modes.

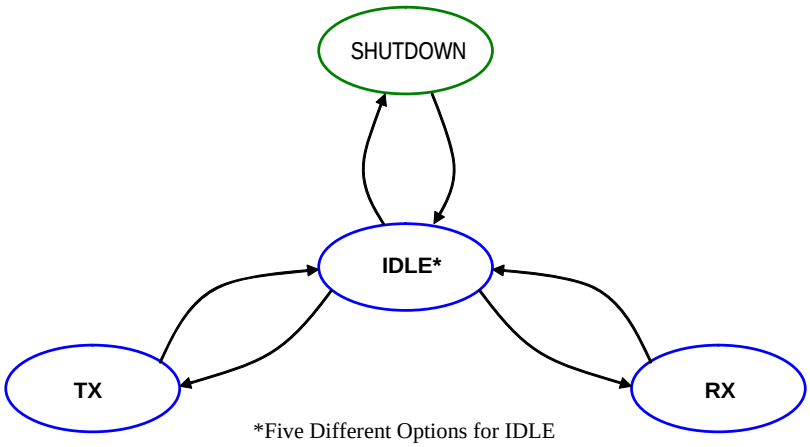


Figure 7. State Machine Diagram

Table 11. Operating Modes Response Time

State/Mode	Response Time to		Current in State /Mode [µA]
	TX	RX	
Shut Down State	16.8 ms	16.8 ms	15 nA
Idle States:			
Standby Mode	800 µs	800 µs	450 nA
Sleep Mode	800 µs	800 µs	1 µA
Sensor Mode	800 µs	800 µs	1 µA
Ready Mode	200 µs	200 µs	800 µA
Tune Mode	200 µs	200 µs	8.5 mA
TX State	NA	200 µs	30 mA @ +13 dBm
RX State	200 µs	NA	18.5 mA

3.2.1. SHUTDOWN State

The SHUTDOWN state is the lowest current consumption state of the device with nominally less than 15 nA of current consumption. The shutdown state may be entered by driving the SDN pin (Pin 20) high. The SDN pin should be held low in all states except the SHUTDOWN state. In the SHUTDOWN state, the contents of the registers are lost and there is no SPI access.

When the chip is connected to the power supply, a POR will be initiated after the falling edge of SDN.

3.2.2. IDLE State

There are five different modes in the IDLE state which may be selected by "Register 07h. Operating Mode and Function Control 1". All modes have a tradeoff between current consumption and response time to TX/RX mode. This tradeoff is shown in Table 11. After the POR event, SWRESET, or exiting from the SHUTDOWN state the chip will default to the IDLE-READY mode. After a POR event the interrupt registers must be read to properly enter the SLEEP, SENSOR, or STANDBY mode and to control the 32 kHz clock correctly.

3.2.2.1. STANDBY Mode

STANDBY mode has the lowest current consumption of the five IDLE states with only the LPLDO enabled to maintain the register values. In this mode the registers can be accessed in both read and write mode. The STANDBY mode can be entered by writing 0h to "Register 07h. Operating Mode and Function Control 1". If an interrupt has occurred (i.e., the nIRQ pin = 0) the interrupt registers must be read to achieve the minimum current consumption. Additionally, the ADC should not be selected as an input to the GPIO in this mode as it will cause excess current consumption.

3.2.2.2. SLEEP Mode

In SLEEP mode the LPLDO is enabled along with the Wake-Up-Timer, which can be used to accurately wake-up the radio at specified intervals. See "8.6. Wake-Up Timer and 32 kHz Clock Source" on page 56 for more information on the Wake-Up-Timer. SLEEP mode is entered by setting enwt = 1 (40h) in "Register 07h. Operating Mode and Function Control 1". If an interrupt has occurred (i.e., the nIRQ pin = 0) the interrupt registers must be read to achieve the minimum current consumption. Also, the ADC should not be selected as an input to the GPIO in this mode as it will cause excess current consumption.

3.2.2.3. SENSOR Mode

In SENSOR mode either the Low Battery Detector, Temperature Sensor, or both may be enabled in addition to the LPLDO and Wake-Up-Timer. The Low Battery Detector can be enabled by setting enlbd = 1 in "Register 07h. Operating Mode and Function Control 1". See "8.4. Temperature Sensor" on page 53 and "8.5. Low Battery Detector" on page 55 for more information on these features. If an interrupt has occurred (i.e., the nIRQ pin = 0) the interrupt registers must be read to achieve the minimum current consumption.

3.2.2.4. READY Mode

READY Mode is designed to give a fast transition time to TX mode with reasonable current consumption. In this mode the Crystal oscillator remains enabled reducing the time required to switch to TX or RX mode by eliminating the crystal start-up time. READY mode is entered by setting xton = 1 in "Register 07h. Operating Mode and Function Control 1". To achieve the lowest current consumption state the crystal oscillator buffer should be disabled in “Register 62h. Crystal Oscillator Control and Test.” To exit READY mode, bufovr (bit 1) of this register must be set back to 0.

3.2.2.5. TUNE Mode

In TUNE mode the PLL remains enabled in addition to the other blocks enabled in the IDLE modes. This will give the fastest response to TX mode as the PLL will remain locked but it results in the highest current consumption. This mode of operation is designed for frequency hopping spread spectrum systems (FHSS). TUNE mode is entered by setting pllon = 1 in "Register 07h. Operating Mode and Function Control 1". It is not necessary to set xton to 1 for this mode, the internal state machine automatically enables the crystal oscillator.

3.2.3. TX State

The TX state may be entered from any of the IDLE modes when the txon bit is set to 1 in "Register 07h. Operating Mode and Function Control 1". A built-in sequencer takes care of all the actions required to transition between states from enabling the crystal oscillator to ramping up the PA. The following sequence of events will occur automatically when going from STANDBY mode to TX mode by setting the txon bit.

1. Enable the main digital LDO and the Analog LDOs.
2. Start up crystal oscillator and wait until ready (controlled byan internal timer).
3. Enable PLL.
4. Calibrate VCO (this action is skipped when the skipvco bit is 1, default value is 0).
5. Wait until PLL settles to required transmit frequency (controlled by an internal timer).
6. Activate power amplifier and wait until power ramping is completed (controlled by an internal timer).
7. Transmit packet.

Steps in this sequence may be eliminated depending on which IDLE mode the chip is configured to prior to setting the txon bit. By default, the VCO and PLL are calibrated every time the PLL is enabled.

3.2.4. RX State

The RX state may be entered from any of the IDLE modes when the rxon bit is set to 1 in "Register 07h. Operating Mode and Function Control 1". A built-in sequencer takes care of all the actions required to transition from one of the IDLE modes to the RX state. The following sequence of events will occur automatically to get the chip into RX mode when going from STANDBY mode to RX mode by setting the rxon bit:

1. Enable the main digital LDO and the Analog LDOs.
2. Start up crystal oscillator and wait until ready (controlled by an internal timer).
3. Enable PLL.
4. Calibrate VCO (this action is skipped when the skipvco bit is 1, default value is 0).
5. Wait until PLL settles to required receive frequency (controlled by an internal timer).
6. Enable receive circuits: LNA, mixers, and ADC.
7. Enable receive mode in the digital modem.

Depending on the configuration of the radio all or some of the following functions will be performed automatically by the digital modem: AGC, AFC (optional), update status registers, bit synchronization, packet handling (optional) including sync word, header check, and CRC.

3.2.5. Device Status

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
02	R	Device Status	ffovfl	ffunfl	rxffem	headerr	freqerr		cps[1]	cps[0]	—

The operational status of the chip can be read from "Register 02h. Device Status".

3.3. Interrupts

The Si4430/31/32 is capable of generating an interrupt signal when certain events occur. The chip notifies the microcontroller that an interrupt event has occurred by setting the nIRQ output pin LOW = 0. This interrupt signal will be generated when any one (or more) of the interrupt events (corresponding to the Interrupt Status bits) shown below occur. The nIRQ pin will remain low until the microcontroller reads the Interrupt Status Register(s) (Registers 03h–04h) containing the active Interrupt Status bit. The nIRQ output signal will then be reset until the next change in status is detected. The interrupts must be enabled by the corresponding enable bit in the Interrupt Enable Registers (Registers 05h–06h). All enabled interrupt bits will be cleared when the microcontroller reads the interrupt status register. If the interrupt is not enabled when the event occurs it will not trigger the nIRQ pin, but the status may still be read at anytime in the Interrupt Status registers.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
03	R	Interrupt Status 1	ifferr	itxffafull	itxffaem	irxffafull	iext	ipksent	ipkvalid	icrcerror	—
04	R	Interrupt Status 2	iswdet	ipreaval	ipreainval	irssi	iwut	ilbd	ichiprdy	ipor	—
05	R/W	Interrupt Enable 1	enfferr	entxffafull	entxffaem	enrxffafull	enext	enpksent	enpkvalid	encrcerror	00h
06	R/W	Interrupt Enable 2	enswdet	enpreaval	enpreainval	enrssi	enwut	enlbd	enchiprdy	enpor	01h

See “AN440: EZRadioPRO Detailed Register Descriptions” for a complete list of interrupts.

3.4. System Timing

The system timing for TX and RX modes is shown in Figures 8 and 9. The figures demonstrate transitioning from STANDBY mode to TX or RX mode through the built-in sequencer of required steps. The user only needs to program the desired mode, and the internal sequencer will properly transition the part from its current mode.

The VCO will automatically calibrate at every frequency change or power up. The PLL T0 time is to allow for bias settling of the VCO. The PLL TS time is for the settling time of the PLL, which has a default setting of 100 µs. The total time for PLL T0, PLL CAL, and PLL TS under all conditions is 200 µs. Under certain applications, the PLL T0 time and the PLL CAL may be skipped for faster turn-around time. Contact applications support if faster turnaround time is desired.

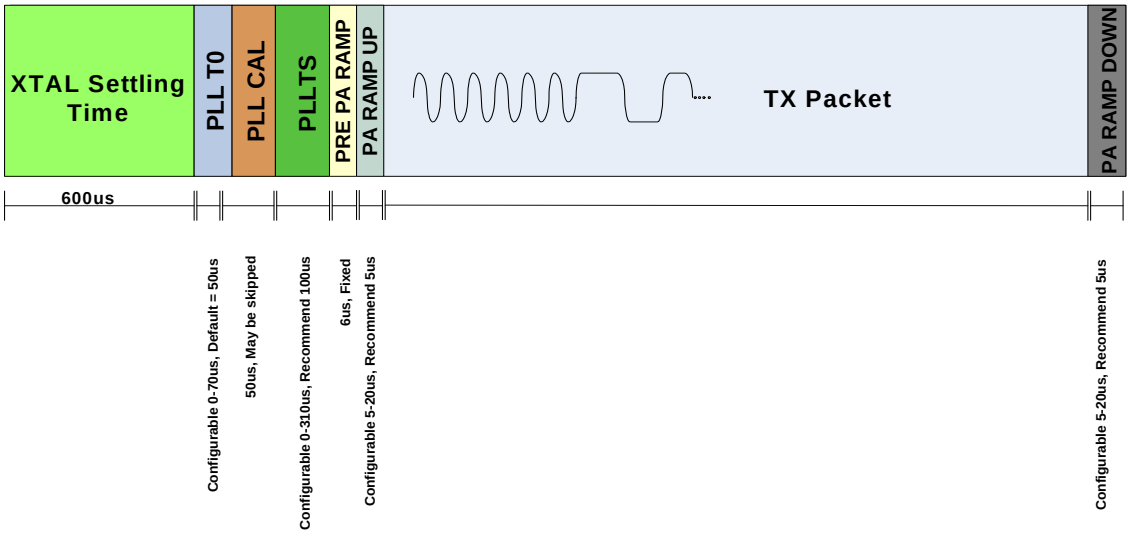


Figure 8. TX Timing

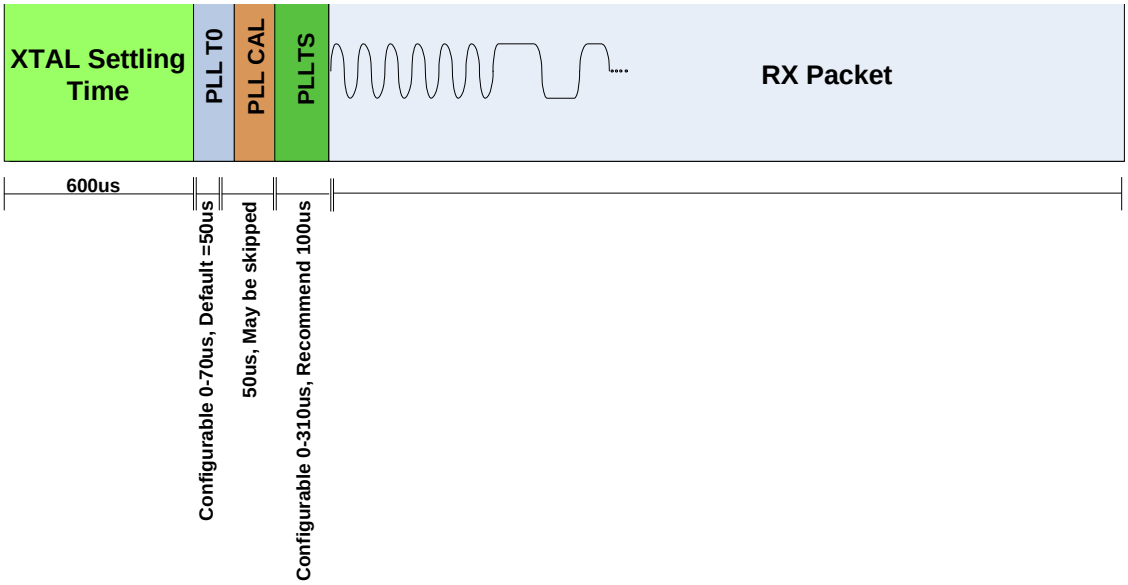


Figure 9. RX Timing

3.5. Frequency Control

For calculating the necessary frequency register settings it is recommended that customers use Silicon Labs' Wireless Design Suite (WDS) or the EZRadioPRO Register Calculator worksheet (in Microsoft Excel) available on the product website. These methods offer a simple method to quickly determine the correct settings based on the application requirements. The following information can be used to calculated these values manually.

3.5.1. Frequency Programming

In order to receive or transmit an RF signal, the desired channel frequency, $f_{carrier}$, must be programmed into the Si4430/31/32. The Si4431/32 and Si4430 cover different frequencies. This section discusses the frequency range covered by all EZRadioPRO devices. Note that this frequency is the center frequency of the desired channel and not an LO frequency. The carrier frequency is generated by a Fractional-N Synthesizer, using 10 MHz both as the reference frequency and the clock of the (3^{rd} order) ΔΣ modulator. This modulator uses modulo 64000 accumulators. This design was made to obtain the desired frequency resolution of the synthesizer. The overall division ratio of the feedback loop consist of an integer part (N) and a fractional part (F).In a generic sense, the output frequency of the synthesizer is as follows:

$$f_{OUT} = 10MHz \times (N + F)$$

The fractional part (F) is determined by three different values, Carrier Frequency (fc[15:0]), Frequency Offset (fo[8:0]), and Frequency Deviation (fd[7:0]). Due to the fine resolution and high loop bandwidth of the synthesizer, FSK modulation is applied inside the loop and is done by varying F according to the incoming data; this is discussed further in "3.5.4. Frequency Deviation" on page 27. Also, a fixed offset can be added to fine-tune the carrier frequency and counteract crystal tolerance errors. For simplicity assume that only the fc[15:0] register will determine the fractional component. The equation for selection of the carrier frequency is shown below:

$$f_{carrier} = 10MHz \times (hbsel + 1) \times (N + F)$$

$$f_{TX} = 10MHz * (hbsel + 1) * (fb[4:0] + 24 + \frac{fc[15:0]}{64000})$$

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
73	R/W	Frequency Offset 1	fo[7]	fo[6]	fo[5]	fo[4]	fo[3]	fo[2]	fo[1]	fo[0]	00h
74	R/W	Frequency Offset 2							fo[9]	fo[8]	00h
75	R/W	Frequency Band Select		sbsel	hbsel	fb[4]	fb[3]	fb[2]	fb[1]	fb[0]	35h
76	R/W	Nominal Carrier Frequency 1	fc[15]	fc[14]	fc[13]	fc[12]	fc[11]	fc[10]	fc[9]	fc[8]	BBh
77	R/W	Nominal Carrier Frequency 0	fc[7]	fc[6]	fc[5]	fc[4]	fc[3]	fc[2]	fc[1]	fc[0]	80h

The integer part (N) is determined by fb[4:0]. Additionally, the output frequency can be halved by connecting a ÷2 divider to the output. This divider is not inside the loop and is controlled by the hbsel bit in "Register 75h. Frequency Band Select." This effectively partitions the entire 240–960 MHz frequency range into two separate bands: High Band (HB) for hbsel = 1, and Low Band (LB) for hbsel = 0. The valid range of fb[4:0] is from 0 to 23. If a higher value is written into the register, it will default to a value of 23. The integer part has a fixed offset of 24 added to it as shown in the formula above. Table 12 demonstrates the selection of fb[4:0] for the corresponding frequency band.

After selection of the fb (N) the fractional component may be solved with the following equation:

$$fc[15:0] = \left(\frac{f_{TX}}{10MHz * (hbsel + 1)} - fb[4:0] - 24 \right) * 64000$$

fb and fc are the actual numbers stored in the corresponding registers.

Table 12. Frequency Band Selection

fb[4:0] Value	N	Frequency Band	
		hbsel=0	hbsel=1
0	24	240–249.9 MHz	480–499.9 MHz
1	25	250–259.9 MHz	500–519.9 MHz
2	26	260–269.9 MHz	520–539.9 MHz
3	27	270–279.9 MHz	540–559.9 MHz
4	28	280–289.9 MHz	560–579.9 MHz
5	29	290–299.9 MHz	580–599.9 MHz
6	30	300–309.9 MHz	600–619.9 MHz
7	31	310–319.9 MHz	620–639.9 MHz
8	32	320–329.9 MHz	640–659.9 MHz
9	33	330–339.9 MHz	660–679.9 MHz
10	34	340–349.9 MHz	680–699.9 MHz
11	35	350–359.9 MHz	700–719.9 MHz
12	36	360–369.9 MHz	720–739.9 MHz
13	37	370–379.9 MHz	740–759.9 MHz
14	38	380–389.9 MHz	760–779.9 MHz
15	39	390–399.9 MHz	780–799.9 MHz
16	40	400–409.9 MHz	800–819.9 MHz
17	41	410–419.9 MHz	820–839.9 MHz
18	42	420–429.9 MHz	840–859.9 MHz
19	43	430–439.9 MHz	860–879.9 MHz
20	44	440–449.9 MHz	880–899.9 MHz
21	45	450–459.9 MHz	900–919.9 MHz
22	46	460–469.9 MHz	920–939.9 MHz
23	47	470–479.9 MHz	940–960 MHz

The chip will automatically shift the frequency of the Synthesizer down by 937.5 kHz (30 MHz ÷ 32) to achieve the correct Intermediate Frequency (IF) when RX mode is entered. Low-side injection is used in the RX Mixing architecture; therefore, no frequency reprogramming is required when using the same TX frequency and switching between RX/TX modes.

3.5.2. Easy Frequency Programming for FHSS

While Registers 73h–77h may be used to program the carrier frequency of the Si4430/31/32, it is often easier to think in terms of “channels” or “channel numbers” rather than an absolute frequency value in Hz. Also, there may be some timing-critical applications (such as for Frequency Hopping Systems) in which it is desirable to change frequency by programming a single register. Once the channel step size is set, the frequency may be changed by a single register corresponding to the channel number. A nominal frequency is first set using Registers 73h–77h, as described above. Registers 79h and 7Ah are then used to set a channel step size and channel number, relative to the nominal setting. The Frequency Hopping Step Size (fhs[7:0]) is set in increments of 10 kHz with a maximum channel step size of 2.56 MHz. The Frequency Hopping Channel Select Register then selects channels based on multiples of the step size.

$$F_{carrier} = Fnom + fhs[7:0] \times (fhch[7:0] \times 10kHz)$$

For example, if the nominal frequency is set to 900 MHz using Registers 73h–77h, the channel step size is set to 1 MHz using "Register 7Ah. Frequency Hopping Step Size," and "Register 79h. Frequency Hopping Channel Select" is set to 5d, the resulting carrier frequency would be 905 MHz. Once the nominal frequency and channel step size are programmed in the registers, it is only necessary to program the fhch[7:0] register in order to change the frequency.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
79	R/W	Frequency Hopping Channel Select	fhch[7]	fhch[6]	fhch[5]	fhch[4]	fhch[3]	fhch[2]	fhch[1]	fhch[0]	00h
7A	R/W	Frequency Hopping Step Size	fhs[7]	fhs[6]	fhs[5]	fhs[4]	fhs[3]	fhs[2]	fhs[1]	fhs[0]	00h

3.5.3. Automatic State Transition for Frequency Change

If registers 79h or 7Ah are changed in either TX or mode, the state machine will automatically transition the chip back to TUNE, change the frequency, and automatically go back to either TX or RX. This feature is useful to reduce the number of SPI commands required in a Frequency Hopping System. This in turn reduces microcontroller activity, reducing current consumption. The exception to this is during TX FIFO mode. If a frequency change is initiated during a TX packet, then the part will complete the current TX packet and will only change the frequency for subsequent packets.

3.5.4. Frequency Deviation

The peak frequency deviation is configurable from ±0.625 to ±320 kHz. The Frequency Deviation (Δf) is controlled by the Frequency Deviation Register (fd), address 71 and 72h, and is independent of the carrier frequency setting. When enabled, regardless of the setting of the hbsel bit (high band or low band), the resolution of the frequency deviation will remain in increments of 625 Hz. When using frequency modulation the carrier frequency will deviate from the nominal center channel carrier frequency by ±Δf:

$$\Delta f = fd[8:0] \times 625Hz$$

$$fd[8:0] = \frac{\Delta f}{625Hz} \quad \Delta f = \textit{peak deviation}$$

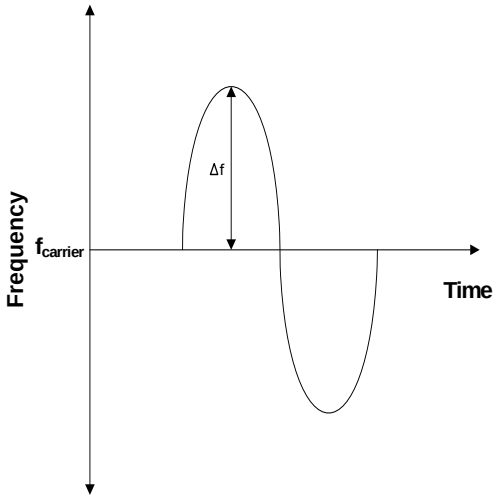


Figure 10. Frequency Deviation

The previous equation should be used to calculate the desired frequency deviation. If desired, frequency modulation may also be disabled in order to obtain an unmodulated carrier signal at the channel center frequency; see "4.1. Modulation Type" on page 32 for further details.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
71	R/W	Modulation Mode Control 2	trclk[1]	trclk[0]	dtmod[1]	dtmod[0]	eninv	fd[8]	modtyp[1]	modtyp[0]	00h
72	R/W	Frequency Deviation	fd[7]	fd[6]	fd[5]	fd[4]	fd[3]	fd[2]	fd[1]	fd[0]	20h

3.5.5. Frequency Offset Adjustment

When the AFC is disabled the frequency offset can be adjusted manually by fo[9:0] in registers 73h and 74h. It is not possible to have both AFC and offset as internally they share the same register. The frequency offset adjustment and the AFC both are implemented by shifting the Synthesizer Local Oscillator frequency. This register is a signed register so in order to get a negative offset it is necessary to take the twos complement of the positive offset number. The offset can be calculated by the following:

$$DesiredOffset = 156.25Hz \times (hbsel + 1) \times fo[9:0]$$

$$fo[9:0] = \frac{DesiredOffset}{156.25Hz \times (hbsel + 1)}$$

The adjustment range in high band is ±160 kHz and in low band it is ±80 kHz. For example to compute an offset of +50 kHz in high band mode fo[9:0] should be set to 0A0h. For an offset of –50 kHz in high band mode the fo[9:0] register should be set to 360h.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
73	R/W	Frequency Offset	fo[7]	fo[6]	fo[5]	fo[4]	fo[3]	fo[2]	fo[1]	fo[0]	00h
74	R/W	Frequency Offset							fo[9]	fo[8]	00h

3.5.6. Automatic Frequency Control (AFC)

All AFC settings can be easily obtained from the settings calculator. This is the recommended method to program all AFC settings. This section is intended to describe the operation of the AFC in more detail to help understand the trade-offs of using AFC.The receiver supports automatic frequency control (AFC) to compensate for frequency differences between the transmitter and receiver reference frequencies. These differences can be caused by the absolute accuracy and temperature dependencies of the reference crystals. Due to frequency offset compensation in the modem, the receiver is tolerant to frequency offsets up to 0.25 times the IF bandwidth when the AFC is disabled. When the AFC is enabled, the received signal will be centered in the pass-band of the IF filter, providing optimal sensitivity and selectivity over a wider range of frequency offsets up to 0.35 times the IF bandwidth. The trade-off of receiver sensitivity (at 1% PER) versus carrier offset and the impact of AFC are illustrated in Figure 11.

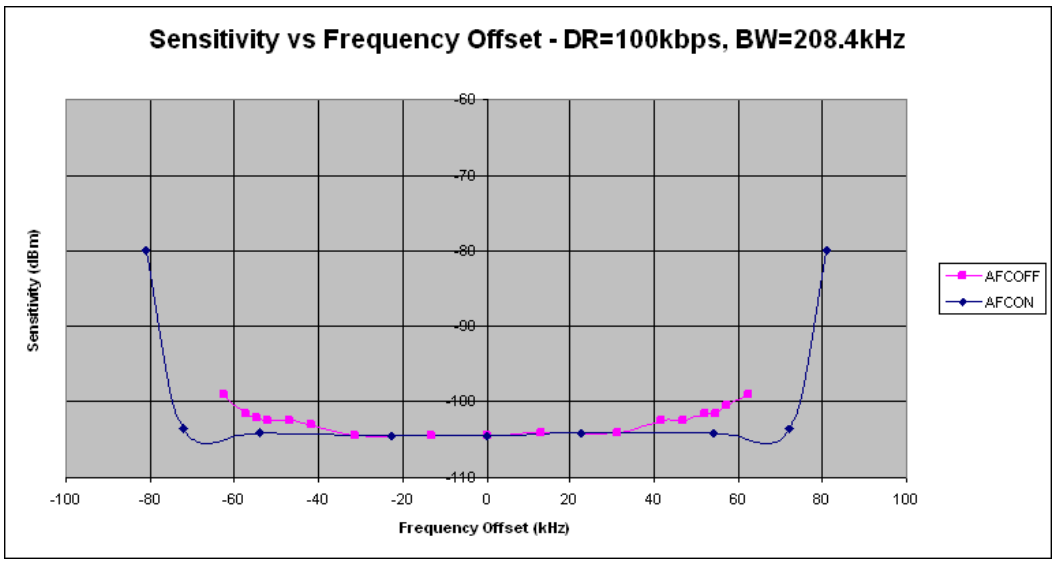


Figure 11. Sensitivity at 1% PER vs. Carrier Frequency Offset

When AFC is enabled, the preamble length needs to be long enough to settle the AFC. In general, one byte of preamble is sufficient to settle the AFC. Disabling the AFC allows the preamble to be shortened from 40 bits to 32 bits. Note that with the AFC disabled, the preamble length must still be long enough to settle the receiver and to detect the preamble (see "6.7. Preamble Length" on page 47). The AFC corrects the detected frequency offset by changing the frequency of the Fractional-N PLL. When the preamble is detected, the AFC will freeze for the remainder of the packet. In multi-packet mode the AFC is reset at the end of every packet and will re-acquire the frequency offset for the next packet. The AFC loop includes a bandwidth limiting mechanism improving the rejection of out of band signals. When the AFC loop is enabled, its pull-in-range is determined by the bandwidth limiter value (AFCLimiter) which is located in register 2Ah.

AFC_pull_in_range = ±AFCLimiter[7:0] x (hbsel+1) x 625 Hz

The AFC Limiter register is an unsigned register and its value can be obtained from the EZRadioPRO Register Calculator spreadsheet.

The amount of error correction feedback to the Fractional-N PLL before the preamble is detected is controlled from afcgearh[2:0]. The default value 000 relates to a feedback of 100% from the measured frequency error and is advised for most applications. Every bit added will half the feedback but will require a longer preamble to settle.

The AFC operates as follows. The frequency error of the incoming signal is measured over a period of two bit times, after which it corrects the local oscillator via the Fractional-N PLL. After this correction, some time is allowed to settle the Fractional-N PLL to the new frequency before the next frequency error is measured. The duration of the AFC cycle before the preamble is detected can be programmed with shwait[2:0]. It is advised to use the default value 001, which sets the AFC cycle to 4 bit times (2 for measurement and 2 for settling). If shwait[2:0] is programmed to 3'b000, there is no AFC correction output. It is advised to use the default value 001, which sets the AFC cycle to 4 bit times (2 for measurement and 2 for settling).

The AFC correction value may be read from register 2Bh. The value read can be converted to kHz with the following formula:

AFC Correction = 156.25Hz x (hbsel +1) x afc_corr[7: 0]

	Frequency Correction	
	RX	**TX**
AFC disabled	Freq Offset Register	Freq Offset Register
AFC enabled	AFC	Freq Offset Register

3.5.7. TX Data Rate Generator

The data rate is configurable between 0.123–256 kbps. For data rates below 30 kbps the ”txdtrtscale” bit in register 70h should be set to 1. When higher data rates are used this bit should be set to 0**.**

The TX date rate is determined by the following formula in bps:

$$DR\_TX\ (bps) = \frac{txdr[15:0] \times 1\ MHz}{2^{16 + 5 \times txdtrtscale}}$$

$$txdr[15:0] = \frac{DR\_TX(bps) \times 2^{16 + 5 \times txdtrtscale}}{1\ MHz}$$

For data rates higher than 100 kbps, Register 58h should be changed from its default of 80h to C0h. Non-optimal modulation and increased eye closure will result if this setting is not made for data rates higher than 100 kbps. The txdr register is only applicable to TX mode and does not need to be programmed for RX mode. The RX bandwidth which is partly determined from the data rate is programmed separately.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
6E	R/W	TX Data Rate 1	txdr[15]	txdr[14]	txdr[13]	txdr[12]	txdr[11]	txdr[10]	txdr[9]	txdr[8]	0Ah
6F	R/W	TX Data Rate 0	txdr[7]	txdr[6]	txdr[5]	txdr[4]	txdr[3]	txdr[2]	txdr[1]	txdr[0]	3Dh

4. Modulation Options

4.1. Modulation Type

The Si4430/31/32 supports three different modulation options: Gaussian Frequency Shift Keying (GFSK), Frequency Shift Keying (FSK), and On-Off Keying (OOK). GFSK is the recommended modulation type as it provides the best performance and cleanest modulation spectrum. Figure 12 demonstrates the difference between FSK and GFSK for a Data Rate of 64 kbps. The time domain plots demonstrate the effects of the Gaussian filtering. The frequency domain plots demonstrate the spectral benefit of GFSK over FSK. The type of modulation is selected with the modtyp[1:0] bits in "Register 71h. Modulation Mode Control 2". Note that it is also possible to obtain an unmodulated carrier signal by setting modtyp[1:0] = 00.

modtyp[1:0]	Modulation Source
00	Unmodulated Carrier
01	OOK
10	FSK
11	GFSK (enable TX Data CLK when direct mode is used)

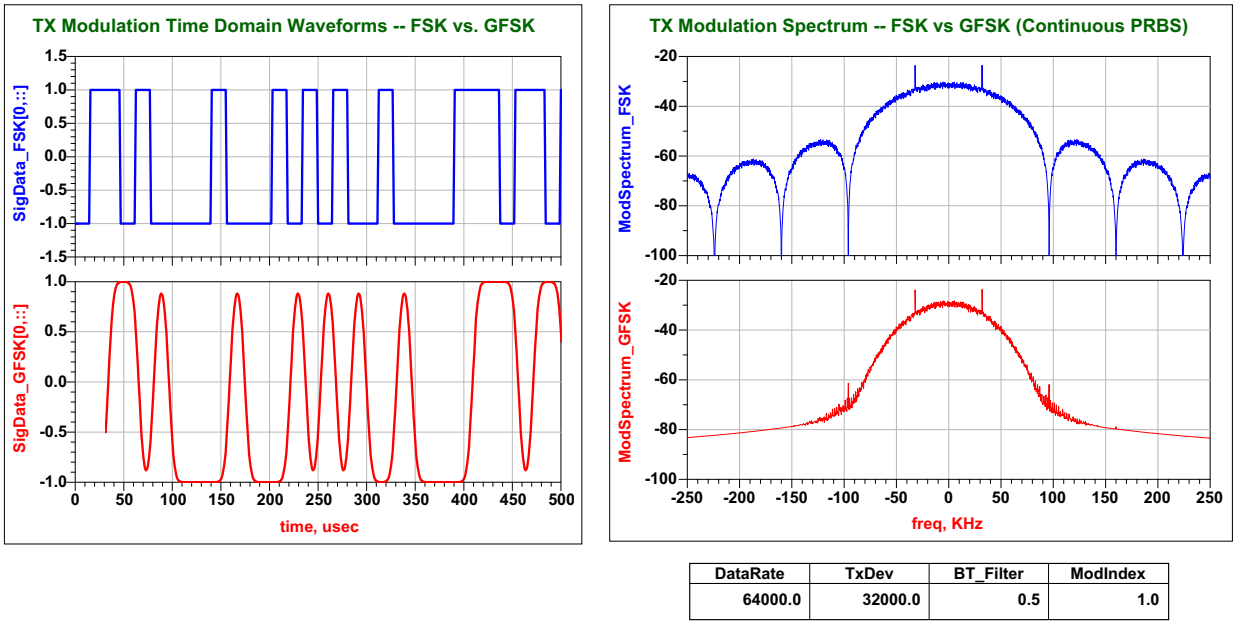


Figure 12. FSK vs GFSK Spectrums

4.2. Modulation Data Source

The Si4430/31/32 may be configured to obtain its modulation data from one of three different sources: FIFO mode, Direct Mode, and from a PN9 mode. In Direct Mode, the TX modulation data may be obtained from several different input pins. These options are set through the dtmod[1:0] field in "Register 71h. Modulation Mode Control 2".

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
71	R/W	Modulation Mode Control 2	trclk[1]	trclk[0]	dtmod[1]	dtmod[0]	eninv	fd[8]	modtyp[1]	modtyp[0]	00h

dtmod[1:0]	Data Source
00	Direct Mode using TX/RX Data via GPIO pin (GPIO configuration required)
01	Direct Mode using TX/RX Data via SDI pin (only when nSEL is high)
10	FIFO Mode
11	PN9 (internally generated)

4.2.1. FIFO Mode

In FIFO mode, the transmit and receive data is stored in integrated FIFO register memory. The FIFOs are accessed via "Register 7Fh. FIFO Access," and are most efficiently accessed with burst read/write operation as discussed in "3.1. Serial Peripheral Interface (SPI)" on page 18.

In TX mode, the data bytes stored in FIFO memory are "packaged" together with other fields and bytes of information to construct the final transmit packet structure. These other potential fields include the Preamble, Sync word, Header, CRC checksum, etc. The configuration of the packet structure in TX mode is determined by the Automatic Packet Handler (if enabled), in conjunction with a variety of Packet Handler Registers (see Table 13 on page 45). If the Automatic Packet Handler is disabled, the entire desired packet structure should be loaded into FIFO memory; no other fields (such as Preamble or Sync word are automatically added to the bytes stored in FIFO memory). For further information on the configuration of the FIFOs for a specific application or packet size, see "6. Data Handling and Packet Handler" on page 41.

In RX mode, only the bytes of the received packet structure that are considered to be "data bytes" are stored in FIFO memory. Which bytes of the received packet are considered "data bytes" is determined by the Automatic Packet Handler (if enabled), in conjunction with the Packet Handler Registers (see Table 13 on page 45). If the Automatic Packet Handler is disabled, all bytes following the Sync word are considered data bytes and are stored in FIFO memory. Thus, even if Automatic Packet Handling operation is not desired, the preamble detection threshold and Sync word still need to be programmed so that the RX Modem knows when to start filling data into the FIFO. When the FIFO is being used in RX mode, all of the received data may still be observed directly (in real-time) by properly programming a GPIO pin as the RXDATA output pin; this can be quite useful during application development.

When in FIFO mode, the chip will automatically exit the TX or RX State when either the ipksent or ipkvalid interrupt occurs. The chip will return to the IDLE mode state programmed in "Register 07h. Operating Mode and Function Control 1". For example, the chip may be placed into TX mode by setting the txon bit, but with the pllon bit additionally set. The chip will transmit all of the contents of the FIFO and the ipksent interrupt will occur. When this interrupt event occurs, the chip will clear the txon bit and return to TUNE mode, as indicated by the set state of the pllon bit. If no other bits are additionally set in register 07h (besides txon initially), then the chip will return to the STANDBY state.

In RX mode, the rxon bit will be cleared if ipkvalid occurs and the rxmpk bit (RX Multi-Packet bit, SPI Register 08h bit [4]) is not set. When the rxmpk bit is set, the part will not exit the RX state after successfully receiving a packet, but will remain in RX mode. The microcontroller will need to decide on the appropriate subsequent action, depending upon information such as an interrupt generated by CRC, packet valid, or preamble detect.

4.2.2. Direct Mode

For legacy systems that perform packet handling within an MCU or other baseband chip, it may not be desirable to use the FIFO. For this scenario, a Direct Mode is provided which bypasses the FIFOs entirely.

In TX direct mode, the TX modulation data is applied to an input pin of the chip and processed in "real time" (i.e., not stored in a register for transmission at a later time). A variety of pins may be configured for use as the TX Data input function.

Furthermore, an additional pin may be required for a TX Clock output function if GFSK modulation is desired (only the TX Data input pin is required for FSK). Two options for the source of the TX Data are available in the dtmod[1:0] field, and various configurations for the source of the TX Data Clock may be selected through the trclk[1:0] field.

trclk[1:0]	TX/RX Data Clock Configuration
00	No TX Clock (only for FSK)
01	TX/RX Data Clock is available via GPIO (GPIO needs programming accordingly as well)
10	TX/RX Data Clock is available via SDO pin (only when nSEL is high)
11	TX/RX Data Clock is available via the nIRQ pin

The eninv bit in SPI Register 71h will invert the TX Data; this is most likely useful for diagnostic and testing purposes.

In RX direct mode, the RX Data and RX Clock can be programmed for direct (real-time) output to GPIO pins. The microcontroller may then process the RX data without using the FIFO or packet handler functions of the RFIC. In RX direct mode, the chip must still acquire bit timing during the Preamble, and thus the preamble detection threshold (SPI Register 35h) must still be programmed. Once the preamble is detected, certain bit timing functions within the RX Modem change their operation for optimized performance over the remainder of the packet. It is not required that a Sync word be present in the packet in RX Direct mode; however, if the Sync word is absent then the skipsyn bit in SPI Register 33h must be set, or else the bit timing and tracking function within the RX Modem will not be configured for optimum performance.

4.2.2.1. Direct Synchronous Mode

In TX direct mode, the chip may be configured for synchronous or asynchronous modes of modulation. In direct synchronous mode, the RFIC is configured to provide a TX Clock signal as an output to the external device that is providing the TX Data stream. This TX Clock signal is a square wave with a frequency equal to the programmed data rate. The external modulation source (e.g., MCU) must accept this TX Clock signal as an input and respond by providing one bit of TX Data back to the RFIC, synchronous with one edge of the TX Clock signal. In this fashion, the rate of the TX Data input stream from the external source is controlled by the programmed data rate of the RFIC; no TX Data bits are made available at the input of the RFIC until requested by another cycle of the TX Clock signal. The TX Data bits supplied by the external source are transmitted directly in real-time (i.e., not stored internally for later transmission).

All modulation types (FSK/GFSK/OOK) are valid in TX direct synchronous mode. As will be discussed in the next section, there are limits on modulation types in TX direct asynchronous mode.

4.2.2.2. Direct Asynchronous Mode

In TX direct asynchronous mode, the RFIC no longer controls the data rate of the TX Data input stream. Instead, the data rate is controlled only by the external TX Data source; the RFIC simply accepts the data applied to its TX Data input pin, at whatever rate it is supplied. This means that there is no longer a need for a TX Clock output signal from the RFIC, as there is no synchronous "handshaking" between the RFIC and the external data source. The TX Data bits supplied by the external source are transmitted directly in real-time (i.e., not stored internally for later transmission).

It is not necessary to program the data rate parameter when operating in TX direct asynchronous mode. The chip still internally samples the incoming TX Data stream to determine when edge transitions occur; however, rather than sampling the data at a pre-programmed data rate, the chip now internally samples the incoming TX Data stream at its maximum possible oversampling rate. This allows the chip to accurately determine the timing of the bit edge transitions without prior knowledge of the data rate. (Of course, it is still necessary to program the desired peak frequency deviation.)

Only FSK and OOK modulation types are valid in TX Direct Asynchronous Mode; GFSK modulation is not available in asynchronous mode. This is because the RFIC does not have knowledge of the supplied data rate, and thus cannot determine the appropriate Gaussian lowpass filter function to apply to the incoming data.

One advantage of this mode that it saves a microcontroller pin because no TX Clock output function is required. The primary disadvantage of this mode is the increase in occupied spectral bandwidth with FSK (as compared to GFSK).

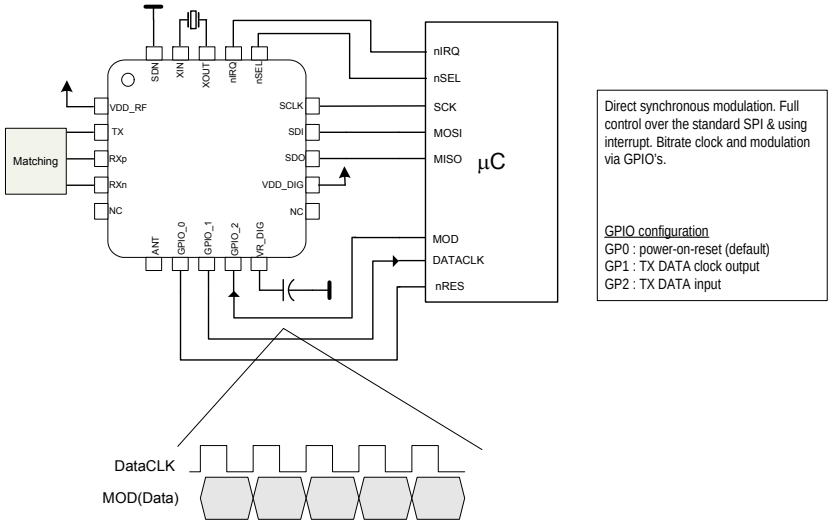


Figure 13. Direct Synchronous Mode Example

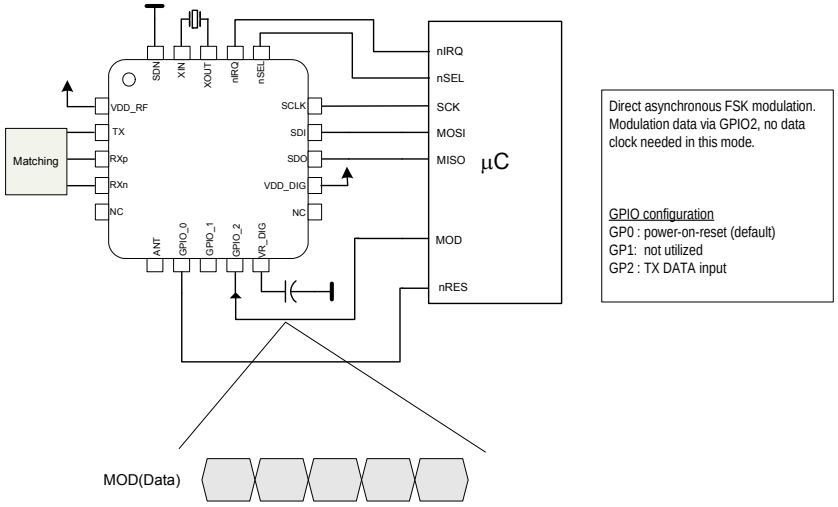


Figure 14. Direct Asynchronous Mode Example

4.2.2.3. Direct Mode using SPI or nIRQ Pins

In certain applications it may be desirable to minimize the connections to the microcontroller or to preserve the GPIOs for other uses. For these cases it is possible to use the SPI pins and nIRQ as the modulation clock and data. The SDO pin can be configured to be the data clock by programming trclk = 10. If the nSEL pin is LOW then the function of the pin will be SPI data output. If the pin is high and trclk[1:0] is 10 then during RX and TX modes the data clock will be available on the SDO pin. If trclk[1:0] is set to 11 and no interrupts are enabled in registers 05 or 06h, then the nIRQ pin can also be used as the TX/RX data clock.

The SDI pin can be configured to be the data source in both RX and TX modes if dtmod[1:0] = 01. In a similar fashion, if nSEL is LOW the pin will function as SPI data-in. If nSEL is HIGH then in TX mode it will be the data to

be modulated and transmitted. In RX mode it will be the received demodulated data. Figure 15 demonstrates using SDI and SDO as the TX/RX data and clock:

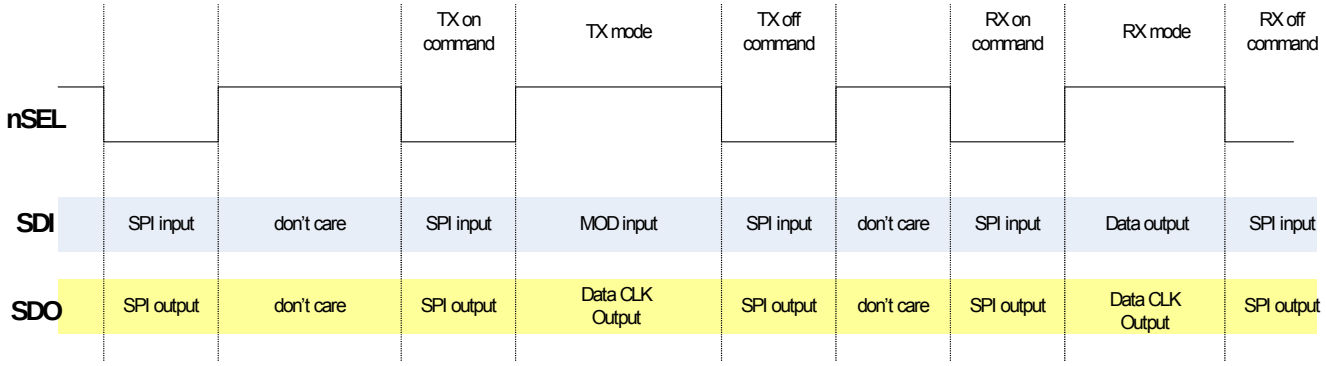


Figure 15. Microcontroller Connections

If the SDO pin is not used for data clock then it may be programmed to be the interrupt function (nIRQ) by programming Reg 0Eh bit 3.

4.2.3. PN9 Mode

In this mode the TX Data is generated internally using a pseudorandom (PN9 sequence) bit generator. The primary purpose of this mode is for use as a test mode to observe the modulated spectrum without having to provide data.

5. Internal Functional Blocks

This section provides an overview some of the key blocks of the internal radio architecture.

5.1. RX LNA

Depending on the part, the input frequency range for the LNA is between 240–960 MHz. The LNA provides gain with a noise figure low enough to suppress the noise of the following stages. The LNA has one step of gain control which is controlled by the analog gain control (AGC) algorithm. The AGC algorithm adjusts the gain of the LNA and PGA so the receiver can handle signal levels from sensitivity to +5 dBm with optimal performance.

In the Si4431, the TX and RX may be tied directly. See the TX/RX direct-tie reference design available on the Silicon Labs website. for more details. When the direct tie is used, the lna_sw bit in “Register 6Dh. TX Power” must be set.

5.2. RX I-Q Mixer

The output of the LNA is fed internally to the input of the receive mixer. The receive mixer is implemented as an I-Q mixer that provides both I and Q channel outputs to the programmable gain amplifier. The mixer consists of two double-balanced mixers whose RF inputs are driven in parallel, local oscillator (LO) inputs are driven in quadrature, and separate I and Q Intermediate Frequency (IF) outputs drive the programmable gain amplifier. The receive LO signal is supplied by an integrated VCO and PLL synthesizer operating between 240–960 MHz. The necessary quadrature LO signals are derived from the divider at the VCO output.

5.3. Programmable Gain Amplifier

The programmable gain amplifier (PGA) provides the necessary gain to boost the signal level into the dynamic range of the ADC. The PGA must also have enough gain switching to allow for large input signals to ensure a linear RSSI range up to –20 dBm. The PGA has steps of 3 dB which are controlled by the AGC algorithm in the digital modem.

5.4. ADC

The amplified IQ IF signals are digitized using an Analog-to-Digital Converter (ADC), which allows for low current consumption and high dynamic range. The bandpass response of the ADC provides exceptional rejection of out of band blockers.

5.5. Digital Modem

Using high-performance ADCs allows channel filtering, image rejection, and demodulation to be performed in the digital domain, resulting in reduced area while increasing flexibility. The digital modem performs the following functions:

- Channel selection filter
- TX modulation
- RX demodulation
- AGC
- Preamble detector
- Invalid preamble detector
- Radio signal strength indicator (RSSI)
- Automatic frequency compensation (AFC)
- Packet handling including EZMAC® features
- Cyclic redundancy check (CRC)

The digital channel filter and demodulator are optimized for ultra low power consumption and are highly configurable. Supported modulation types are GFSK, FSK, and OOK. The channel filter can be configured to support bandwidths ranging from 620 kHz down to 2.6 kHz. A large variety of data rates are supported ranging from 0.123 up to 256 kbps. The AGC algorithm is implemented digitally using an advanced control loop optimized for fast response time.

The configurable preamble detector is used to improve the reliability of the sync-word detection. The sync-word detector is only enabled when a valid preamble is detected, significantly reducing the probability of false detection.

The received signal strength indicator (RSSI) provides a measure of the signal strength received on the tuned channel. The resolution of the RSSI is 0.5 dB. This high resolution RSSI enables accurate channel power measurements for clear channel assessment (CCA), carrier sense (CS), and listen before talk (LBT) functionality.

Frequency mistuning caused by crystal inaccuracies can be compensated by enabling the digital automatic frequency control (AFC) in receive mode.

A comprehensive programmable packet handler including key features of Silicon Labs' EZMAC is integrated to create a variety of communication topologies ranging from peer-to-peer networks to mesh networks. The extensive programmability of the packet header allows for advanced packet filtering which in turn enables a mix of broadcast, group, and point-to-point communication.

A wireless communication channel can be corrupted by noise and interference, and it is therefore important to know if the received data is free of errors. A cyclic redundancy check (CRC) is used to detect the presence of erroneous bits in each packet. A CRC is computed and appended at the end of each transmitted packet and verified by the receiver to confirm that no errors have occurred. The packet handler and CRC can significantly reduce the load on the system microcontroller allowing for a simpler and cheaper microcontroller.

The digital modem includes the TX modulator which converts the TX data bits into the corresponding stream of digital modulation values to be summed with the fractional input to the sigma-delta modulator. This modulation approach results in highly accurate resolution of the frequency deviation. A Gaussian filter is implemented to support GFSK, considerably reducing the energy in the adjacent channels. The default bandwidth-time product (BT) is 0.5 for all programmed data rates, but it may be adjusted to other values.

5.6. Synthesizer

An integrated Sigma Delta (ΣΔ) Fractional-N PLL synthesizer capable of operating from 240–960 MHz is provided on-chip. The Si4431/32 and Si4430 cover different frequencies. This section discusses the frequency range covered by all EZRadioPRO devices. Using a ΣΔ synthesizer has many advantages; it provides flexibility in choosing data rate, deviation, channel frequency, and channel spacing. The transmit modulation is applied directly to the loop in the digital domain through the fractional divider which results in very precise accuracy and control over the transmit deviation.

Depending on the part, the PLL and Δ-Σ modulator scheme is designed to support any desired frequency and channel spacing in the range from 240–960 MHz with a frequency resolution of 156.25 Hz (Low band) or 312.5 Hz (High band). The transmit data rate can be programmed between 0.123–256 kbps, and the frequency deviation can be programmed between ±1–320 kHz. These parameters may be adjusted via registers as shown in "3.5. Frequency Control" on page 25.

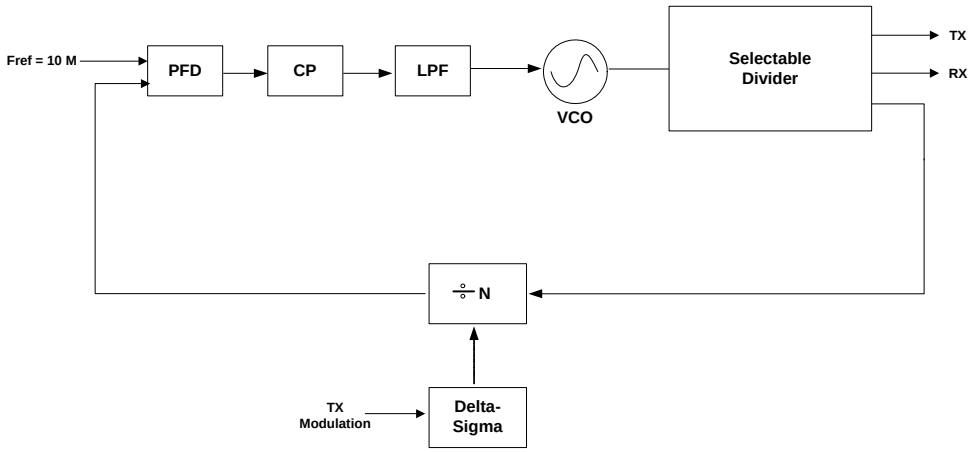


Figure 16. PLL Synthesizer Block Diagram

The reference frequency to the PLL is 10 MHz. The PLL utilizes a differential L-C VCO, with integrated on-chip inductors. The output of the VCO is followed by a configurable divider which will divide down the signal to the desired output frequency band. The modulus of the variable divide-by-N divider stage is controlled dynamically by

the output from the Δ-Σ modulator. The tuning resolution is sufficient to tune to the commanded frequency with a maximum accuracy of 312.5 Hz anywhere in the range between 240–960 MHz.

5.6.1. VCO

The output of the VCO is automatically divided down to the correct output frequency depending on the hbsel and fb[4:0] fields in "Register 75h. Frequency Band Select." In receive mode, the LO frequency is automatically shifted downwards by the IF frequency of 937.5 kHz, allowing transmit and receive operation on the same frequency. The VCO integrates the resonator inductor and tuning varactor, so no external VCO components are required.

The VCO uses a capacitance bank to cover the wide frequency range specified. The capacitance bank will automatically be calibrated every time the synthesizer is enabled. In certain fast hopping applications this might not be desirable so the VCO calibration may be skipped by setting the appropriate register.

5.7. Power Amplifier

The Si4432 contains an internal integrated power amplifier (PA) capable of transmitting at output levels between +1 and +20 dBm. The Si4431/4430 contains a PA which is capable of transmitting output levels between –8 to +13 dBm. The PA design is single-ended and is implemented as a two stage class CE amplifier with a high efficiency when transmitting at maximum power. The PA efficiency can only be optimized at one power level. Changing the output power by adjusting txpow[2:0] will scale both the output power and current but the efficiency will not remain constant. The PA output is ramped up and down to prevent unwanted spectral splatter.

In the Si4431, the TX and RX may be tied directly. See the TX/RX direct-tie reference design available on the Silicon Labs website for more details. When the direct tie is used, the lna_sw bit in “Register 6Dh. TX Power” must be set to 1.

5.7.1. Output Power Selection

The output power is configurable in 3 dB steps with the txpow[2:0] field in "Register 6Dh. TX Power." Extra output power can allow the use of a cheaper smaller antenna, greatly reducing the overall BOM cost. The higher power setting of the chip achieves maximum possible range, but of course comes at the cost of higher TX current consumption. However, depending on the duty cycle of the system, the effect on battery life may be insignificant. Contact Silicon Labs Support for help in evaluating this tradeoff.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
6D	R/W	TX Power	reserved	reserved	reserved	reserved	lna_sw	txpow[2]	txpow[1]	txpow[0]	18h

txpow[2:0]	Si4432 Output Power
000	+1 dBm
001	+2 dBm
010	+5 dBm
011	+8 dBm
100	+11 dBm
101	+14 dBm
110	+17 dBm
111	+20 dBm

txpow[2:0]	Si4431/30 Output Power
000	–8 dBm
001	–5 dBm
010	–2 dBm
011	+1 dBm
100	+4 dBm
101	+7 dBm
110	+10 dBm
111	+13 dBm

5.8. Crystal Oscillator

The Si4430/31/32 includes an integrated 30 MHz crystal oscillator with a fast start-up time of less than 600 µs when a suitable parallel resonant crystal is used. The design is differential with the required crystal load capacitance integrated on-chip to minimize the number of external components. By default, all that is required off-chip is the 30 MHz crystal.

The crystal load capacitance can be digitally programmed to accommodate crystals with various load capacitance requirements and to adjust the frequency of the crystal oscillator. The tuning of the crystal load capacitance is programmed through the xlc[6:0] field of "Register 09h. 30 MHz Crystal Oscillator Load Capacitance." The total internal capacitance is 12.5 pF and is adjustable in approximately 127 steps (97fF/step). The xtalshift bit provides a coarse shift in frequency but is not binary with xlc[6:0].

The crystal frequency adjustment can be used to compensate for crystal production tolerances. Utilizing the on-chip temperature sensor and suitable control software, the temperature dependency of the crystal can be canceled.

The typical value of the total on-chip capacitance Cint can be calculated as follows:

$$Cint = 1.8\ pF + 0.085\ pF \times xlc[6:0] + 3.7\ pF \times xtalshift$$

Note that the coarse shift bit xtalshift is not binary with xlc[6:0]. The total load capacitance Cload seen by the crystal can be calculated by adding the sum of all external parasitic PCB capacitances Cext to Cint. If the maximum value of Cint (16.3 pF) is not sufficient, an external capacitor can be added for exact tuning. Additional information on calculating Cext and crystal selection guidelines is provided in “AN417: Si4x3x Family Crystal Oscillator.”

If AFC is disabled then the synthesizer frequency may be further adjusted by programming the Frequency Offset field fo[9:0]in "Register 73h. Frequency Offset 1" and "Register 74h. Frequency Offset 2", as discussed in "3.5. Frequency Control" on page 25.

The crystal oscillator frequency is divided down internally and may be output to the microcontroller through one of the GPIO pins for use as the System Clock. In this fashion, only one crystal oscillator is required for the entire system and the BOM cost is reduced. The available clock frequencies and GPIO configuration are discussed further in "8.2. Microcontroller Clock" on page 51.

The Si4430/31/32 may also be driven with an external 30 MHz clock signal through the XOUT pin. When driving with an external reference or using a TCXO, the XTAL load capacitance register should be set to 0.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
09	R/W	Crystal Oscillator Load Capacitance	xtalshift	xlc[6]	xlc[5]	xlc[4]	xlc[3]	xlc[2]	xlc[1]	xlc[0]	7Fh

5.9. Regulators

There are a total of six regulators integrated onto the Si4430/31/32. With the exception of the digital regulator, all regulators are designed to operate with only internal decoupling. The digital regulator requires an external 1 µF decoupling capacitor. All regulators are designed to operate with an input supply voltage from +1.8 to +3.6 V. The output stage of the of PA is not connected internally to a regulator and is connected directly to the battery voltage.

A supply voltage should only be connected to the VDD pins. No voltage should be forced on the digital regulator output.

6. Data Handling and Packet Handler

The internal modem is designed to operate with a packet including a 010101... preamble structure. To configure the modem to operate with packet formats without a preamble or other legacy packet structures contact customer support.

6.1. RX and TX FIFOs

Two 64 byte FIFOs are integrated into the chip, one for RX and one for TX, as shown in Figure 17. "Register 7Fh. FIFO Access" is used to access both FIFOs. A burst write, as described in "3.1. Serial Peripheral Interface (SPI)" on page 18, to address 7Fh will write data to the TX FIFO. A burst read from address 7Fh will read data from the RX FIFO.

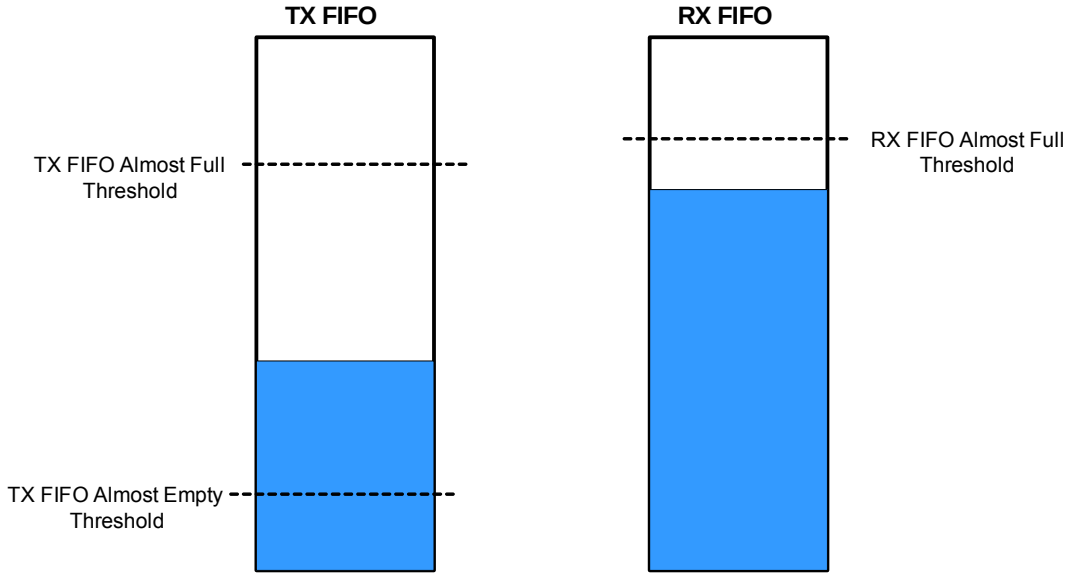


Figure 17. FIFO Thresholds

The TX FIFO has two programmable thresholds. An interrupt event occurs when the data in the TX FIFO reaches these thresholds. The first threshold is the FIFO almost full threshold, txafthr[5:0]. The value in this register corresponds to the desired threshold value in number of bytes. When the data being filled into the TX FIFO crosses this threshold limit, an interrupt to the microcontroller is generated so the chip can enter TX mode to transmit the contents of the TX FIFO. The second threshold for TX is the FIFO almost empty threshold, txaethr[5:0]. When the data being shifted out of the TX FIFO drops below the almost empty threshold an interrupt will be generated. If more data is not loaded into the FIFO then the chip automatically exits the TX State after the ipksent interrupt occurs. The chip will return to the mode selected by the remaining bits in SPI Register 07h. For example, the chip may be placed into TX mode by setting the txon bit, but with the xton bit additionally set. For this condition, the chip will transmit all of the contents of the FIFO and the ipksent interrupt will occur. When this interrupt event occurs, the chip will clear the txon bit and return to READY mode, as indicated by the set state of the xton bit. If the pllon bit D1 is set when entering TX mode (i.e., SPI Register 07h = 0Ah), the chip will exit from TX mode after sending the packet and return to TUNE mode.

However, the chip will not automatically return to STANDBY mode upon exit from the TX state, in the event the TX packet is initiated by setting SPI Register 07h = 08h (i.e., setting only txon bit D3). The chip will instead return to READY mode, with the crystal oscillator remaining enabled. This is intentional; the system may be configured such that the host MCU derives its clock from the MCU_CLK output of the RFIC (through GPIO2), and this clock signal must not be shut down without allowing the host MCU time to process any interrupt signals that may have occurred. The host MCU must subsequently perform a WRITE to SPI Register 07h = 00h to enter STANDBY mode and obtain minimum current consumption.

Add	R/W	Function/ Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
08	R/W	Operating & Function Control 2	antdiv[2]	antdiv[1]	antdiv[0]	rxmpk	autotx	enldm	ffclrrx	ffclrtx	00h
7C	R/W	TX FIFO Control 1	Reserved	Reserved	txafthr[5]	txafthr[4]	txafthr[3]	txafthr[2]	txafthr[1]	txafthr[0]	37h
7D	R/W	TX FIFO Control 2	Reserved	Reserved	txaethr[5]	txaethr[4]	txaethr[3]	txaethr[2]	txaethr[1]	txaethr[0]	04h

The RX FIFO has one programmable threshold called the FIFO Almost Full Threshold, rxafthr[5:0]. When the incoming RX data crosses the Almost Full Threshold an interrupt will be generated to the microcontroller via the nIRQ pin. The microcontroller will then need to read the data from the RX FIFO.

Add	R/W	Function/ Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
7E	R/W	RX FIFO Control	Reserved	Reserved	rxafthr[5]	rxafthr[4]	rxafthr[3]	rxafthr[2]	rxafthr[1]	rxafthr[0]	37h

Both the TX and RX FIFOs may be cleared or reset with the ffclrtx and ffclrrx bits. All interrupts may be enabled by setting the Interrupt Enabled bits in "Register 05h. Interrupt Enable 1" and “Register 06h. Interrupt Enable 2.” If the interrupts are not enabled the function will not generate an interrupt on the nIRQ pin but the bits will still be read correctly in the Interrupt Status registers.

6.2. Packet Configuration

When using the FIFOs, automatic packet handling may be enabled for TX mode, RX mode, or both. "Register 30h. Data Access Control" through “Register 4Bh. Received Packet Length” control the configuration, status, and decoded RX packet data for Packet Handling. The usual fields for network communication (such as preamble, synchronization word, headers, packet length, and CRC) can be configured to be automatically added to the data payload. The fields needed for packet generation normally change infrequently and can therefore be stored in registers. Automatically adding these fields to the data payload greatly reduces the amount of communication between the microcontroller and the Si4430/31/32 and reduces the required computational power of the microcontroller.

The general packet structure is shown in Figure 18. The length of each field is shown below the field. The preamble pattern is always a series of alternating ones and zeroes, starting with a zero. All the fields have programmable lengths to accommodate different applications. The most common CRC polynominals are available for selection.

Figure 18. Packet Structure

An overview of the packet handler configuration registers is shown in Table 13.

6.3. Packet Handler TX Mode

If the TX packet length is set the packet handler will send the number of bytes in the packet length field before returning to IDLE mode and asserting the packet sent interrupt. To resume sending data from the FIFO the microcontroller needs to command the chip to re-enter TX mode. Figure 19 provides an example transaction where the packet length is set to three bytes.

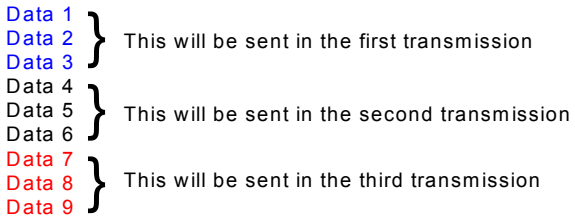


Figure 19. Multiple Packets in TX Packet Handler

6.4. Packet Handler RX Mode

6.4.1. Packet Handler Disabled

When the packet handler is disabled certain fields in the received packet are still required. Proper modem operation requires preamble and sync when the FIFO is being used, as shown in Figure 20. Bits after sync will be treated as raw data with no qualification. This mode allows for the creation of a custom packet handler when the automatic qualification parameters are not sufficient. Manchester encoding is supported but data whitening, CRC, and header checks are not.

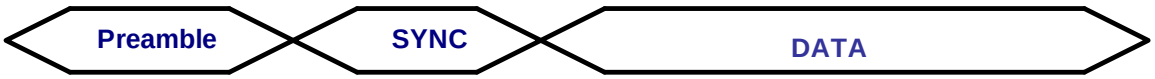


Figure 20. Required RX Packet Structure with Packet Handler Disabled

6.4.2. Packet Handler Enabled

When the packet handler is enabled, all the fields of the packet structure need to be configured. Register contents are used to construct the header field and length information encoded into the transmitted packet when transmitting. The receive FIFO can be configured to handle packets of fixed or variable length with or without a header. If multiple packets are desired to be stored in the FIFO, then there are options available for the different fields that will be stored into the FIFO. Figure 21 demonstrates the options and settings available when multiple packets are enabled. Figure 22 demonstrates the operation of fixed packet length and correct/incorrect packets.

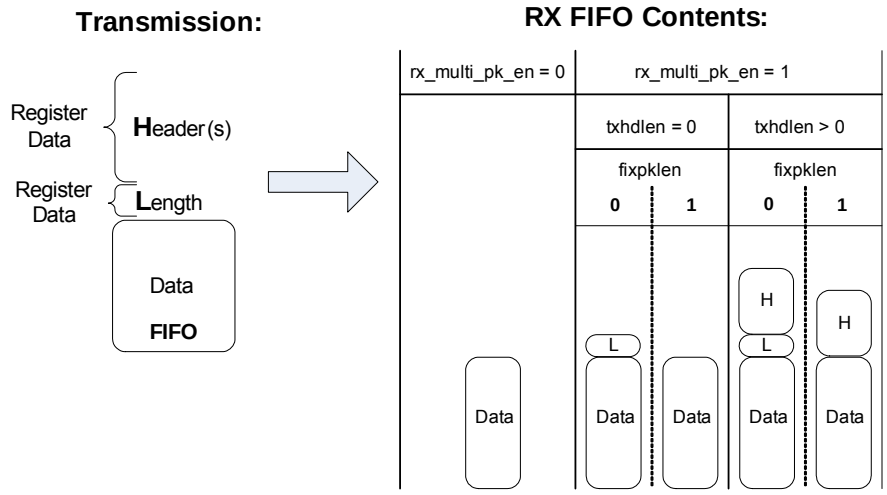


Figure 21. Multiple Packets in RX Packet Handler

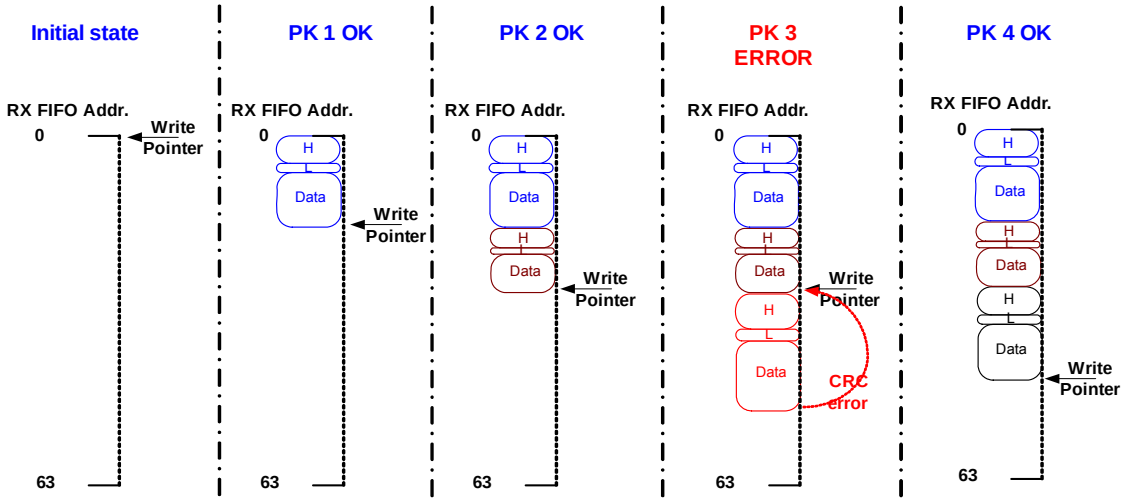


Figure 22. Multiple Packets in RX with CRC or Header Error

Table 13. Packet Handler Registers

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
30	R/W	Data Access Control	enpacrx	lsbfrst	crcdonly	skip2ph	enpactx	encrc	crc[1]	crc[0]	8Dh
31	R	EzMAC status	0	rxcrc1	pksrch	pkrx	pkvalid	crcerror	pktx	pksent	—
32	R/W	Header Control 1	bcen[3:0]				hdch[3:0]				0Ch
33	R/W	Header Control 2	skipsyn	hdlen[2]	hdlen[1]	hdlen[0]	fixpklen	synclen[1]	synclen[0]	prealen[8]	22h
34	R/W	Preamble Length	prealen[7]	prealen[6]	prealen[5]	prealen[4]	prealen[3]	prealen[2]	prealen[1]	prealen[0]	08h
35	R/W	Preamble Detection Control	preath[4]	preath[3]	preath[2]	preath[1]	preath[0]	rssi_off[2]	rssi_off[1]	rssi_off[0]	2Ah
36	R/W	Sync Word 3	sync[31]	sync[30]	sync[29]	sync[28]	sync[27]	sync[26]	sync[25]	sync[24]	2Dh
37	R/W	Sync Word 2	sync[23]	sync[22]	sync[21]	sync[20]	sync[19]	sync[18]	sync[17]	sync[16]	D4h
38	R/W	Sync Word 1	sync[15]	sync[14]	sync[13]	sync[12]	sync[11]	sync[10]	sync[9]	sync[8]	00h
39	R/W	Sync Word 0	sync[7]	sync[6]	sync[5]	sync[4]	sync[3]	sync[2]	sync[1]	sync[0]	00h
3A	R/W	Transmit Header 3	txhd[31]	txhd[30]	txhd[29]	txhd[28]	txhd[27]	txhd[26]	txhd[25]	txhd[24]	00h
3B	R/W	Transmit Header 2	txhd[23]	txhd[22]	txhd[21]	txhd[20]	txhd[19]	txhd[18]	txhd[17]	txhd[16]	00h
3C	R/W	Transmit Header 1	txhd[15]	txhd[14]	txhd[13]	txhd[12]	txhd[11]	txhd[10]	txhd[9]	txhd[8]	00h
3D	R/W	Transmit Header 0	txhd[7]	txhd[6]	txhd[5]	txhd[4]	txhd[3]	txhd[2]	txhd[1]	txhd[0]	00h
3E	R/W	Transmit Packet Length	pklen[7]	pklen[6]	pklen[5]	pklen[4]	pklen[3]	pklen[2]	pklen[1]	pklen[0]	00h
3F	R/W	Check Header 3	chhd[31]	chhd[30]	chhd[29]	chhd[28]	chhd[27]	chhd[26]	chhd[25]	chhd[24]	00h
40	R/W	Check Header 2	chhd[23]	chhd[22]	chhd[21]	chhd[20]	chhd[19]	chhd[18]	chhd[17]	chhd[16]	00h
41	R/W	Check Header 1	chhd[15]	chhd[14]	chhd[13]	chhd[12]	chhd[11]	chhd[10]	chhd[9]	chhd[8]	00h
42	R/W	Check Header 0	chhd[7]	chhd[6]	chhd[5]	chhd[4]	chhd[3]	chhd[2]	chhd[1]	chhd[0]	00h
43	R/W	Header Enable 3	hden[31]	hden[30]	hden[29]	hden[28]	hden[27]	hden[26]	hden[25]	hden[24]	FFh
44	R/W	Header Enable 2	hden[23]	hden[22]	hden[21]	hden[20]	hden[19]	hden[18]	hden[17]	hden[16]	FFh
45	R/W	Header Enable 1	hden[15]	hden[14]	hden[13]	hden[12]	hden[11]	hden[10]	hden[9]	hden[8]	FFh
46	R/W	Header Enable 0	hden[7]	hden[6]	hden[5]	hden[4]	hden[3]	hden[2]	hden[1]	hden[0]	FFh
47	R	Received Header 3	rxhd[31]	rxhd[30]	rxhd[29]	rxhd[28]	rxhd[27]	rxhd[26]	rxhd[25]	rxhd[24]	—
48	R	Received Header 2	rxhd[23]	rxhd[22]	rxhd[21]	rxhd[20]	rxhd[19]	rxhd[18]	rxhd[17]	rxhd[16]	—
49	R	Received Header 1	rxhd[15]	rxhd[14]	rxhd[13]	rxhd[12]	rxhd[11]	rxhd[10]	rxhd[9]	rxhd[8]	—
4A	R	Received Header 0	rxhd[7]	rxhd[6]	rxhd[5]	rxhd[4]	rxhd[3]	rxhd[2]	rxhd[1]	rxhd[0]	—
4B	R	Received Packet Length	rxplen[7]	rxplen[6]	rxplen[5]	rxplen[4]	rxplen[3]	rxplen[2]	rxplen[1]	rxplen[0]	—

6.5. Data Whitening, Manchester Encoding, and CRC

Data whitening can be used to avoid extended sequences of 0s or 1s in the transmitted data stream to achieve a more uniform spectrum. When enabled, the payload data bits are XORed with a pseudorandom sequence output from the built-in PN9 generator. The generator is initialized at the beginning of the payload. The receiver recovers the original data by repeating this operation. Manchester encoding can be used to ensure a dc-free transmission and good synchronization properties. When Manchester encoding is used, the effective datarate is unchanged but the actual datarate (preamble length, etc.) is doubled due to the nature of the encoding. The effective datarate when using Manchester encoding is limited to 128 kbps. The implementation of Manchester encoding is shown in Figure 24. Data whitening and Manchester encoding can be selected with "Register 70h. Modulation Mode Control 1". The CRC is configured via "Register 30h. Data Access Control." Figure 23 demonstrates the portions of the packet which have Manchester encoding, data whitening, and CRC applied. CRC can be applied to only the data portion of the packet or to the data, packet length and header fields. Figure 24 provides an example of how the Manchester encoding is done and also the use of the Manchester invert (enmaniv) function.

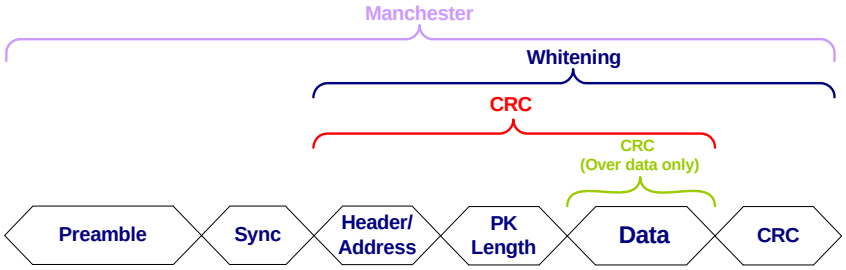


Figure 23. Operation of Data Whitening, Manchester Encoding, and CRC

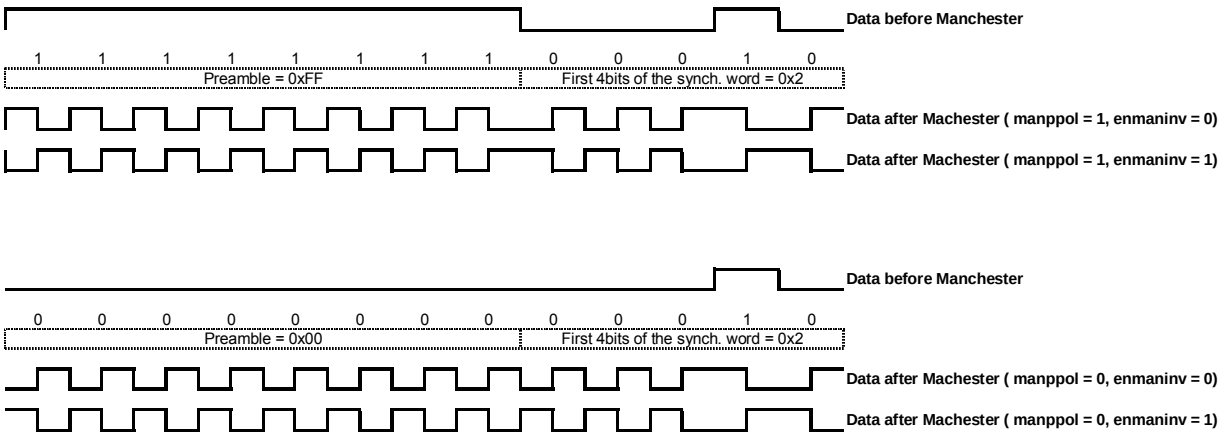


Figure 24. Manchester Coding Example

6.6. Preamble Detector

The Si4430/31/32 has integrated automatic preamble detection. The preamble length is configurable from 1–255 bytes using the prealen[7:0] field in "Register 33h. Header Control 2" and "Register 34h. Preamble Length", as described in “6.2. Packet Configuration”. The preamble detection threshold, preath[4:0] as set in "Register 35h. Preamble Detection Control 1", is in units of 4 bits. The preamble detector searches for a preamble pattern with a length of preath[4:0].

If a false preamble detect occurs, the receiver will continuing searching for the preamble when no sync word is detected. Once preamble is detected (false or real) then the part will then start searching for sync. If no sync occurs then a timeout will occur and the device will initiate search for preamble again. The timeout period is defined as the sync word length plus four bits and will start after a non-preamble pattern is recognized after a valid preamble detection. The preamble detector output may be programmed onto one of the GPIO or read in the interrupt status registers.

6.7. Preamble Length

The preamble detection threshold determines the number of valid preamble bits the radio must receive to qualify a valid preamble. The preamble threshold should be adjusted depending on the nature of the application. The required preamble length threshold will depend on when receive mode is entered in relation to the start of the transmitted packet and the length of the transmit preamble. With a shorter than recommended preamble detection threshold the probability of false detection is directly related to how long the receiver operates on noise before the transmit preamble is received. False detection on noise may cause the actual packet to be missed. The preamble detection threshold is programmed in register 35h. For most applications with a preamble length longer than 32 bits the default value of 20 is recommended for the preamble detection threshold. A shorter Preamble Detection Threshold may be chosen if occasional false detections may be tolerated. When antenna diversity is enabled a 20-bit preamble detection threshold is recommended. When the receiver is synchronously enabled just before the start of the packet, a shorter preamble detection threshold may be used. Table 14 demonstrates the recommended preamble detection threshold and preamble length for various modes.

It is possible to use Si4432/31/30 in a raw mode without the requirement for a 010101... preamble. Contact customer support for further details.

Table 14. Minimum Receiver Settling Time

Mode	Approximate Receiver Settling Time	Recommended Preamble Length with 8-Bit Detection Threshold	Recommended Preamble Length with 20-Bit Detection Threshold
(G)FSK AFC Disabled	1 byte	20 bits	32 bits
(G)FSK AFC Enabled	2 byte	28 bits	40 bits
(G)FSK AFC Disabled +Antenna Diversity Enabled	1 byte	—	64 bits
(G)FSK AFC Enabled +Antenna Diversity Enabled	2 byte	—	8 byte
OOK	2 byte	3 byte	4 byte
OOK + Antenna Diversity Enabled	8 byte	—	8 byte

Note: The recommended preamble length and preamble detection threshold listed above are to achieve 0% PER. They may be shortened when occasional packet errors are tolerable.

6.8. Invalid Preamble Detector

When scanning channels in a frequency hopping system it is desirable to determine if a channel is valid in the minimum amount of time. The preamble detector can output an invalid preamble detect signal. which can be used to identify the channel as invalid. After a configurable time set in Register 60h[7:4], an invalid preamble detect signal is asserted indicating an invalid channel. The period for evaluating the signal for invalid preamble is defined as (inv_pre_th[3:0] x 4) x Bit Rate Period. The preamble detect and invalid preamble detect signals are available in "Register 03h. Interrupt/Status 1" and “Register 04h. Interrupt/Status 2.”

6.9. Synchronization Word Configuration

The synchronization word length for both TX and RX can be configured in Reg 33h, synclen[1:0]. The expected or transmitted sync word can be configured from 1 to 4 bytes as defined below:

- synclen[1:0] = 00—Expected/Transmitted Synchronization Word (sync word) 3.
- synclen[1:0] = 01—Expected/Transmitted Synchronization Word 3 first, followed by sync word 2.
- synclen[1:0] = 10—Expected/Transmitted Synchronization Word 3 first, followed by sync word 2, followed by sync word 1.
- synclen[1:0] = 1—Send/Expect Synchronization Word 3 first, followed by sync word 2, followed by sync word 1, followed by sync word 0.

The sync is transmitted or expected in the following sequence: sync 3→sync 2→sync 1→sync 0. The sync word values can be programmed in Registers 36h–39h. After preamble detection, the part will search for sync for a fixed

period of time. If a sync is not recognized in this period, a timeout will occur, and the search for preamble will be re-initiated. The timeout period after preamble detections is defined as the value programmed into the sync word length plus four additional bits.

6.10. Receive Header Check

The header check is designed to support 1–4 bytes and broadcast headers. The header length needs to be set in register 33h, hdlen[2:0]. The headers to be checked need to be set in register 32h, hdch[3:0]. For instance, there can be four bytes of header in the packet structure but only one byte of the header is set to be checked (i.e., header 3). For the headers that are set to be checked, the expected value of the header should be programmed in chhd[31:0] in Registers 3F–42. The individual bits within the selected bytes to be checked can be enabled or disabled with the header enables, hden[31:0] in Registers 43–46. For example, if you want to check all bits in header 3 then hden[31:24] should be set to FF but if only the last 4 bits are desired to be checked then it should be set to 00001111 (0F). Broadcast headers can also be programmed by setting bcen[3:0] in Register 32h. For broadcast header check the value may be either “FFh” or the value stored in the Check Header register. A logic equivalent of the header check for Header 3 is shown in Figure 25. A similar logic check will be done for Header 2, Header 1, and Header 0 if enabled.

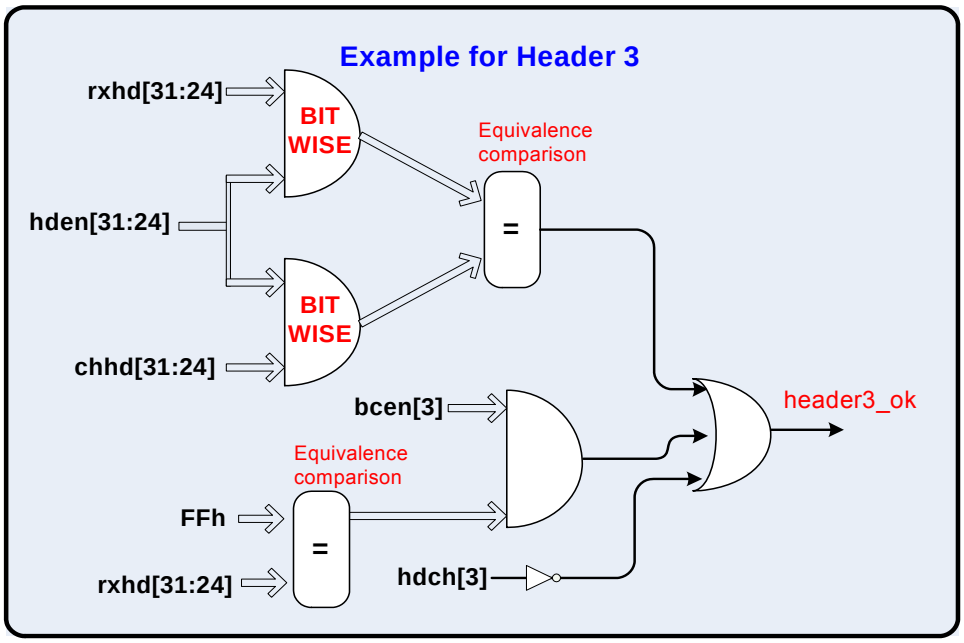


Figure 25. Header

6.11. TX Retransmission and Auto TX

The Si4430/31/32 is capable of automatically retransmitting the last packet loaded in the TX FIFO. Automatic retransmission is set by entering the TX state with the txon bit without reloading the TX FIFO. This feature is useful for beacon transmission or when retransmission is required due to the absence of a valid acknowledgement. Only packets that fit completely in the TX FIFO can be automatically retransmitted.

An automatic transmission function is available, allowing the radio to automatically start or stop a transmission depending on the amount of data in the TX FIFO.

When autotx is set in “Register 08. Operating & Function Control 2", the transceiver will automatically enter the TX state when the TX FIFO almost full threshold is exceeded. Packets will be transmitted according to the configured packet length. To stop transmitting, clear the packet sent or TX FIFO almost empty interrupts must be cleared by reading register.

7. RX Modem Configuration

A Microsoft Excel parameter calculator or Wireless Development Suite (WDS) calculator is provided to determine the proper settings for the modem. The calculator can be found on www.silabs.com or on the CD provided with the demo kits. An application note is available to describe how to use the calculator and to provide advanced descriptions of the modem settings and calculations.

7.1. Modem Settings for FSK and GFSK

The modem performs channel selection and demodulation in the digital domain. The channel filter bandwidth is configurable from 2.6 to 620 kHz. The receiver data-rate, modulation index, and bandwidth are set via registers 1C–25h. The modulation index is equal to 2 times the peak deviation divided by the data rate (Rb).

When Manchester coding is disabled, the required channel filter bandwidth is calculated as BW = 2Fd + Rb where Fd is the frequency deviation and Rb is the data rate.

8. Auxiliary Functions

8.1. Smart Reset

The Si4430/31/32 contains an enhanced integrated SMART RESET or POR circuit. The POR circuit contains both a classic level threshold reset as well as a slope detector POR. This reset circuit was designed to produce a reliable reset signal under any circumstances. Reset will be initiated if any of the following conditions occur:

- Initial power on, VDD starts from gnd: reset is active till VDD reaches V_{RR} (see table);
- When VDD decreases below V_{LD} for any reason: reset is active till VDD reaches V_{RR};
- A software reset via “Register 08h. Operating Mode and Function Control 2”: reset is active for time T_{SWRST}
- On the rising edge of a VDD glitch when the supply voltage exceeds the following time functioned limit:

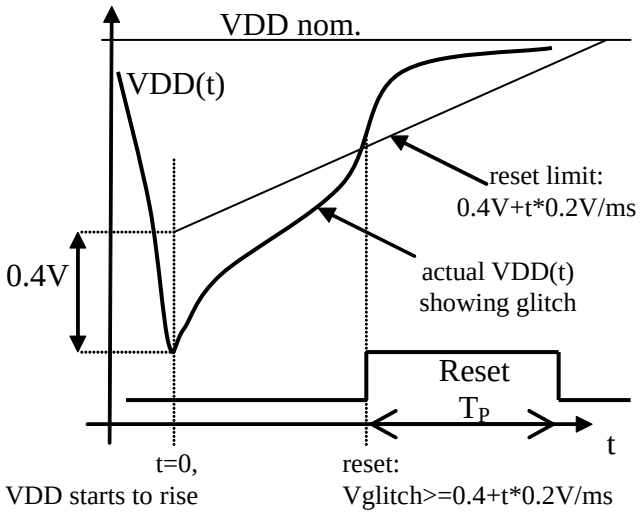


Figure 26. POR Glitch Parameters

Table 15. POR Parameters

Parameter	Symbol	Comment	Min	Typ	Max	Unit
Release Reset Voltage	VRR		0.85	1.3	1.75	V
Power-On VDD Slope	SVDD	tested VDD slope region	0.03		300	V/ms
Low VDD Limit	VLD	VLD<VRR is guaranteed	0.7	1	1.3	V
Software Reset Pulse	TSWRST		50		470	us
Threshold Voltage	VTSD			0.4		V
Reference Slope	k			0.2		V/ms
VDD Glitch Reset Pulse	TP	Also occurs after SDN, and initial power on	5	16	40	ms

The reset will initialize all registers to their default values. The reset signal is also available for output and use by the microcontroller by using the default setting for GPIO_0. The inverted reset signal is available by default on GPIO_1.

8.2. Microcontroller Clock

The 30 MHz crystal oscillator frequency is divided down internally and may be output to the microcontroller through GPIO2. This feature is useful to lower BOM cost by using only one crystal in the system. The system clock frequency is selectable from one of 8 options, as shown below. Except for the 32.768 kHz option, all other frequencies are derived by dividing the crystal oscillator frequency. The 32.768 kHz clock signal is derived from an internal RC oscillator or an external 32 kHz crystal. The default setting for GPIO2 is to output the microcontroller clock signal with a frequency of 1 MHz.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
0A	R/W	Microcontroller Output Clock			clkt[1]	clkt[0]	enlfc	mclk[2]	mclk[1]	mclk[0]	06h

mclk[2:0]	Clock Frequency
000	30 MHz
001	15 MHz
010	10 MHz
011	4 MHz
100	3 MHz
101	2 MHz
110	1 MHz
111	32.768 kHz

If the microcontroller clock option is being used there may be the need of a system clock for the microcontroller while the Si4430/31/32 is in SLEEP mode. Since the crystal oscillator is disabled in SLEEP mode in order to save current, the low-power 32.768 kHz clock can be automatically switched to become the microcontroller clock. This feature is called enable low frequency clock and is enabled by the enlfc bit in “Register 0Ah. Microcontroller Output Clock." When enlfc = 1 and the chip is in SLEEP mode then the 32.768 kHz clock will be provided to the microcontroller as the system clock, regardless of the setting of mclk[2:0]. For example, if mclk[2:0] = 000, 30 MHz will be provided through the GPIO output pin to the microcontroller as the system clock in all IDLE, TX, or RX states. When the chip enters SLEEP mode, the system clock will automatically switch to 32.768 kHz from the RC oscillator or 32.768 XTAL.

Another available feature for the microcontroller clock is the clock tail, clkt[1:0] in “Register 0Ah. Microcontroller Output Clock." If the low frequency clock feature is not enabled (enlfc = 0), then the system clock to the microcontroller is disabled in SLEEP mode. However, it may be useful to provide a few extra cycles for the microcontroller to complete its operation prior to the shutdown of the system clock signal. Setting the clkt[1:0] field will provide additional cycles of the system clock before it shuts off.

clkt[1:0]	Clock Tail
00	0 cycles
01	128 cycles
10	256 cycles
11	512 cycles

If an interrupt is triggered, the microcontroller clock will remain enabled regardless of the selected mode. As soon as the interrupt is read the state machine will then move to the selected mode. The minimum current consumption will not be achieved until the interrupt is read. For instance, if the chip is commanded to SLEEP mode but an interrupt has occurred the 30 MHz XTAL will not be disabled until the interrupt has been cleared.

8.3. General Purpose ADC

An 8-bit SAR ADC is integrated for general purpose use, as well as for digitizing the on-chip temperature sensor reading. Registers 0Fh "ADC Configuration", 10h "Sensor Offset" and 4Fh "Amplifier Offset" can be used to configure the ADC operation. Details of these registers are in “AN440: EZRadioPRO Detailed Register Descriptions.”

Every time an ADC conversion is desired, bit 7 "adcstart/adcdone" in Register 0Fh “ADC Configuration” must be set to 1. The conversion time for the ADC is 350 µs. After the ADC conversion is done and the adcdone signal is showing 1, then the ADC value may be read out of “Register 11h: ADC Value." When the ADC is doing its conversion, the adcstart/adcdone bit will read 0. When the ADC has finished its conversion, the bit will be set to 1. A new ADC conversion can be initiated by writing a 1 to the adcstart/adcdone bit.

The architecture of the ADC is shown in Figure 27. The signal and reference inputs of the ADC are selected by adcsel[2:0] and adcref[1:0] in register 0Fh “ADC Configuration”, respectively. The default setting is to read out the temperature sensor using the bandgap voltage (VBG) as reference. With the VBG reference the input range of the ADC is from 0–1.02 V with an LSB resolution of 4 mV (1.02/255). Changing the ADC reference will change the LSB resolution accordingly.

A differential multiplexer and amplifier are provided for interfacing external bridge sensors. The gain of the amplifier is selectable by adcgain[1:0] in Register 0Fh. The majority of sensor bridges have supply voltage (VDD) dependent gain and offset. The reference voltage of the ADC can be changed to either $V_{DD}/2$ or $V_{DD}/3$. A programmable V_{DD} dependent offset voltage can be added using soffs[3:0] in register 10h.

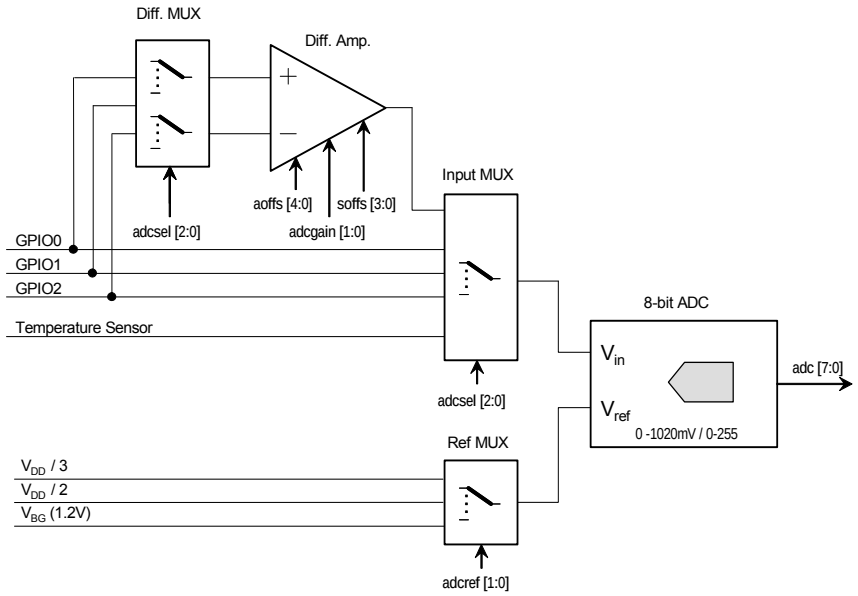


Figure 27. General Purpose ADC Architecture

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
0F	R/W	ADC Configuration	adcstart/adcdone	adcsel[2]	adcsel[1]	adcsel[0]	adcref[1]	adcref[0]	adcgain[1]	adcgain[0]	00h
10	R/W	Sensor Offset					soffs[3]	soffs[2]	soffs[1]	soffs[0]	00h
11	R	ADC Value	adc[7]	adc[6]	adc[5]	adc[4]	adc[3]	adc[2]	adc[1]	adc[0]	—

8.4. Temperature Sensor

An integrated on-chip analog temperature sensor is available. The temperature sensor will be automatically enabled when the temperature sensor is selected as the input of the ADC or when the analog temp voltage is selected on the analog test bus. The temperature sensor value may be digitized using the general-purpose ADC and read out over the SPI through "Register 10h. ADC Sensor Amplifier Offset." The range of the temperature sensor is configurable. Table 16 lists the settings for the different temperature ranges and performance.

To use the Temp Sensor:

1. Set the input for ADC to the temperature sensor, "Register 0Fh. ADC Configuration"—adcsel[2:0] = 000
2. Set the reference for ADC, "Register 0Fh. ADC Configuration"—adcref[1:0] = 00
3. Set the temperature range for ADC, "Register 12h. Temperature Sensor Calibration"—tsrange[1:0]
4. Set entsoffs = 1, "Register 12h. Temperature Sensor Calibration"
5. Trigger ADC reading, "Register 0Fh. ADC Configuration"—adcstart = 1
6. Read temperature value—Read contents of "Register 11h. ADC Value"

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
12	R/W	Temperature Sensor Control	tsrange[1]	tsrange[0]	entsoffs	entstrim	tstrim[3]	tstrim[2]	vbgtrim[1]	vbgtrim[0]	20h
13	R/W	Temperature Value Offset	tvoffs[7]	tvoffs[6]	tvoffs[5]	tvoffs[4]	tvoffs[3]	tvoffs[2]	tvoffs[1]	tvoffs[0]	00h

Table 16. Temperature Sensor Range

entoff	tsrange[1]	tsrange[0]	Temp. range	Unit	Slope	ADC8 LSB
1	0	0	–64 … 64	°C	8 mV/°C	0.5 °C
1	0	1	–64 … 192	°C	4 mV/°C	1 °C
1	1	0	0 … 128	°C	8 mV/°C	0.5 °C
1	1	1	–40 … 216	°F	4 mV/°F	1 °F
0*	1	0	0 … 341	°K	3 mV/°K	1.333 °K
***Note:** Absolute temperature mode, no temperature shift. This mode is only for test purposes. POR value of EN_TOFF is 1.						

The slope of the temperature sensor is very linear and monotonic. For absolute accuracy better than 10 °C calibration is necessary. The temperature sensor may be calibrated by setting entsoffs = 1 in “Register 12h. Temperature Sensor Control” and setting the offset with the tvoffs[7:0] bits in “Register 13h. Temperature Value Offset.” This method adds a positive offset digitally to the ADC value that is read in “Register 11h. ADC Value.” The other method of calibration is to use the tstrim which compensates the analog circuit. This is done by setting entstrim = 1 and using the tstrim[2:0] bits to offset the temperature in “Register 12h. Temperature Sensor Control.” With this method of calibration, a negative offset may be achieved. With both methods of calibration better than ±3 °C absolute accuracy may be achieved.

The different ranges for the temperature sensor and ADC8 are demonstrated in Figure 28. The value of the ADC8 may be translated to a temperature reading by ADC8Value x ADC8 LSB + Lowest Temperature in Temp Range. For instance for a tsrange = 00, Temp = ADC8Value x 0.5 – 64.

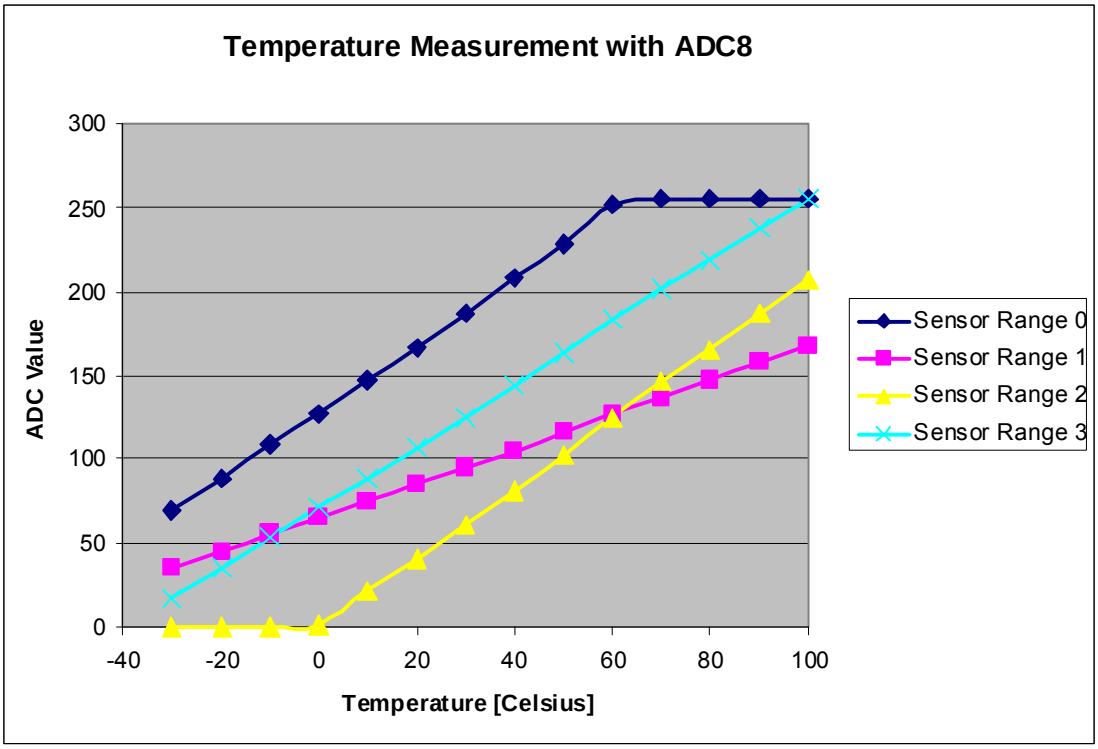


Figure 28. Temperature Ranges using ADC8

8.5. Low Battery Detector

A low battery detector (LBD) with digital read-out is integrated into the chip. A digital threshold may be programmed into the lbdt[4:0] field in "Register 1Ah. Low Battery Detector Threshold." When the digitized battery voltage reaches this threshold an interrupt will be generated on the nIRQ pin to the microcontroller. The microcontroller can confirm source of the interrupt by reading "Register 03h. Interrupt/Status 1" and “Register 04h. Interrupt/Status 2.”

If the LBD is enabled while the chip is in SLEEP mode, it will automatically enable the RC oscillator which will periodically turn on the LBD circuit to measure the battery voltage. The battery voltage may also be read out through "Register 1Bh. Battery Voltage Level" at any time when the LBD is enabled. The low battery detect function is enabled by setting enlbd=1 in "Register 07h. Operating Mode and Function Control 1".

Ad	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
1A	R/W	Low Battery Detector Threshold				lbdt[4]	lbdt[3]	lbdt[2]	lbdt[1]	lbdt[0]	14h
1B	R	Battery Voltage Level	0	0	0	vbat[4]	vbat[3]	vbat[2]	vbat[1]	vbat[0]	—

The LBD output is digitized by a 5-bit ADC. When the LBD function is enabled (enlbd = 1 in "Register 07h. Operating Mode and Function Control 1") the battery voltage may be read at anytime by reading "Register 1Bh. Battery Voltage Level." A battery voltage threshold may be programmed in “Register 1Ah. Low Battery Detector Threshold." When the battery voltage level drops below the battery voltage threshold an interrupt will be generated on the nIRQ pin to the microcontroller if the LBD interrupt is enabled in “Register 06h. Interrupt Enable 2.” The microcontroller will then need to verify the interrupt by reading the interrupt status register, addresses 03 and 04h. The LSB step size for the LBD ADC is 50 mV, with the ADC range demonstrated in the table below. If the LBD is enabled the LBD and ADC will automatically be enabled every 1 s for approximately 250 µs to measure the voltage which minimizes the current consumption in Sensor mode. Before an interrupt is activated four consecutive readings are required.

$$BatteryVoltage = 1.7 + 50mV \times ADCValue$$

ADC Value	VDD Voltage [V]
0	< 1.7
1	1.7–1.75
2	1.75–1.8
…	…
29	3.1–3.15
30	3.15–3.2
31	> 3.2

8.6. Wake-Up Timer and 32 kHz Clock Source

The chip contains an integrated wake-up timer which can be used to periodically wake the chip from SLEEP mode. The wake-up timer runs from the internal 32.768 kHz RC Oscillator. The wake-up timer can be configured to run when in SLEEP mode. If enwt = 1 in "Register 07h. Operating Mode and Function Control 1" when entering SLEEP mode, the wake-up timer will count for a time specified defined in Registers 14–16h, "Wake Up Timer Period." At the expiration of this period an interrupt will be generated on the nIRQ pin if this interrupt is enabled. The microcontroller will then need to verify the interrupt by reading the Registers 03h–04h, "Interrupt Status 1 & 2". The wake-up timer value may be read at any time by the wtv[15:0] read only registers 17h–18h.

The formula for calculating the Wake-Up Period is the following:

$$WUT = \frac{4 \times M \times 2^{R}}{32.768} ms$$

WUT Register	Description
wtr[4:0]	R Value in Formula
wtm[15:0]	M Value in Formula

Use of the D variable in the formula is only necessary if finer resolution is required than can be achieved by using the R value.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
14	R/W	Wake-Up Timer Period 1				wtr[4]	wtr[3]	wtr[2]	wtr[1]	wtr[0]	03h
15	R/W	Wake-Up Timer Period 2	wtm[15]	wtm[14]	wtm[13]	wtm[12]	wtm[11]	wtm[10]	wtm[9]	wtm[8]	00h
16	R/W	Wake-Up Timer Period 3	wtm[7]	wtm[6]	wtm[5]	wtm[4]	wtm[3]	wtm[2]	wtm[1]	wtm[0]	00h
17	R	Wake-Up Timer Value 1	wtv[15]	wtv[14]	wtv[13]	wtv[12]	wtv[11]	wtv[10]	wtv[9]	wtv[8]	—
18	R	Wake-Up Timer Value 2	wtv[7]	wtv[6]	wtv[5]	wtv[4]	wtv[3]	wtv[2]	wtv[1]	wtv[0]	—

There are two different methods for utilizing the wake-up timer (WUT) depending on if the WUT interrupt is enabled in “Register 06h. Interrupt Enable 2.” If the WUT interrupt is enabled then nIRQ pin will go low when the timer expires. The chip will also change state so that the 30 MHz XTAL is enabled so that the microcontroller clock output is available for the microcontroller to use to process the interrupt. The other method of use is to not enable the WUT interrupt and use the WUT GPIO setting. In this mode of operation the chip will not change state until commanded by the microcontroller. The different modes of operating the WUT and the current consumption impacts are demonstrated in Figure 29.

A 32 kHz XTAL may also be used for better timing accuracy. By setting the x32 ksel bit in Register 07h "Operating & Function Control 1", GPIO0 is automatically reconfigured so that an external 32 kHz XTAL may be connected to this pin. In this mode, the GPIO0 is extremely sensitive to parasitic capacitance, so only the XTAL should be connected to this pin with the XTAL physically located as close to the pin as possible. Once the x32 ksel bit is set, all internal functions such as WUT, micro-controller clock, and LDC mode will use the 32 kHz XTAL and not the 32 kHz RC oscillator.

The 32 kHz XTAL accuracy is comprised of both the XTAL parameters and the internal circuit. The XTAL accuracy can be defined as the XTAL initial error + XTAL aging + XTAL temperature drift + detuning from the internal oscillator circuit. The error caused by the internal circuit is typically less than 10 ppm.

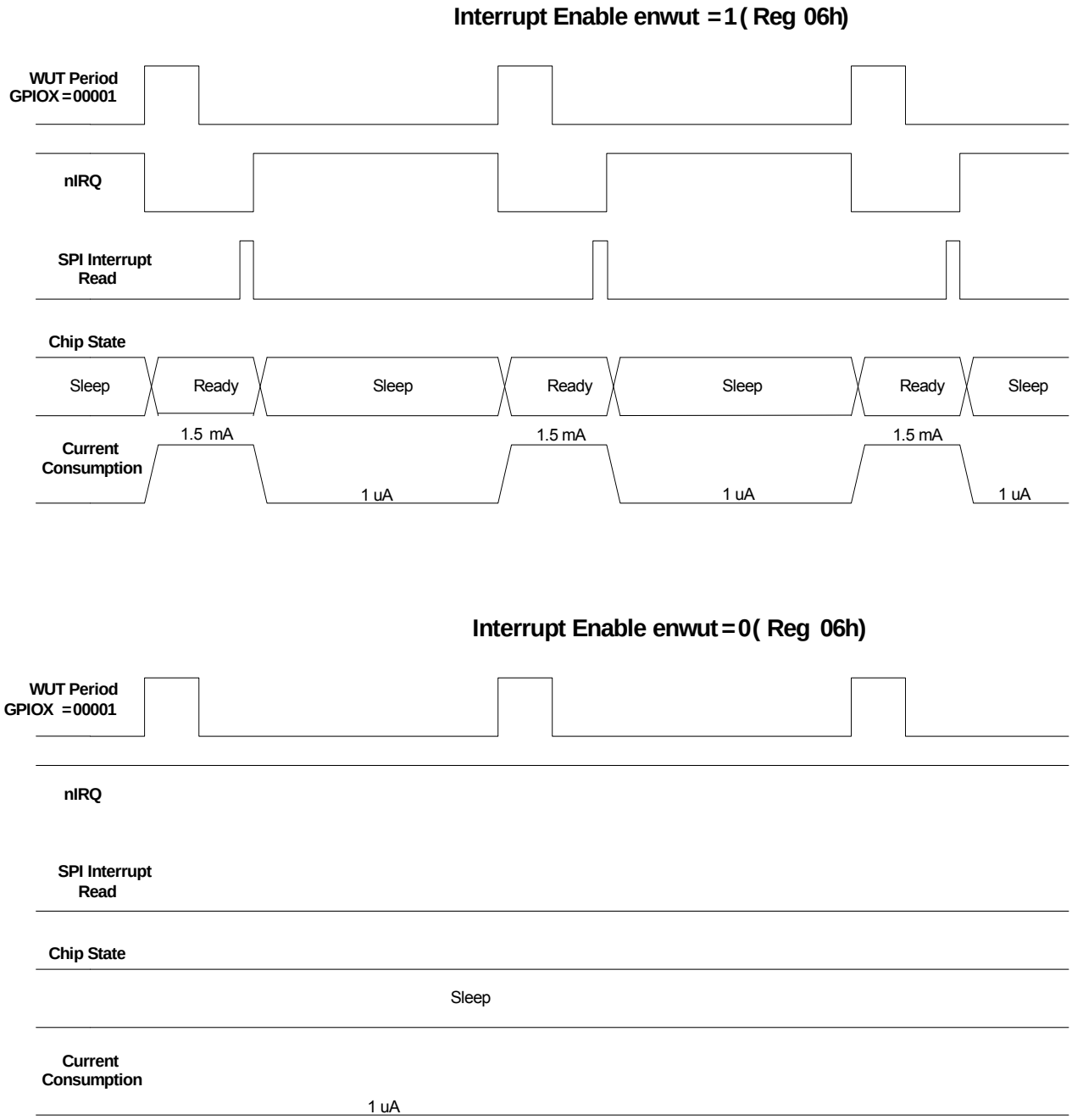


Figure 29. WUT Interrupt and WUT Operation

8.7. Low Duty Cycle Mode

The Low Duty Cycle Mode is available to automatically wake-up the receiver to check if a valid signal is available. The basic operation of the low duty cycle mode is demonstrated in the figure below. If a valid preamble or sync word is not detected the chip will return to sleep mode until the beginning of a new WUT period. If a valid preamble and sync are detected the receiver on period will be extended for the low duty cycle mode duration (TLDC) to receive all of the packet. The WUT period must be set in conjunction with the low duty cycle mode duration. The R value (“Register 14h. Wake-up Timer Period 1”) is shared between the WUT and the TLDC. The ldc[7:0] bits are located in “Register 19h. Low Duty Cycle Mode Duration.” The time of the TLDC is determined by the formula below:

$$TLDC = ldc[7:0] \times \frac{4 \times 2^{R}}{32.768}\ ms$$

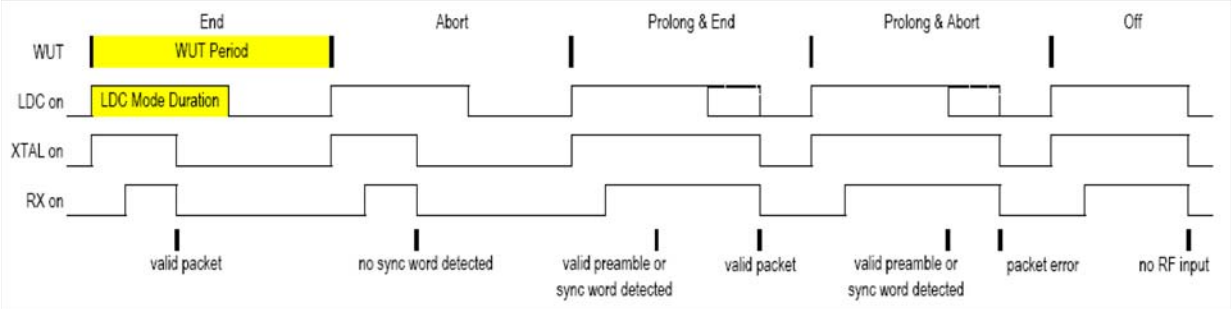


Figure 30. Low Duty Cycle Mode

8.8. GPIO Configuration

Three general purpose IOs (GPIOs) are available. Numerous functions such as specific interrupts, TRSW control, Microcontroller Output, etc. can be routed to the GPIO pins as shown in the tables below. When in Shutdown mode all the GPIO pads are pulled low.

Note: The ADC should not be selected as an input to the GPIO in standby or sleep modes and will cause excess current consumption.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
0B	R/W	GPIO0 Configuration	gpio0drv[1]	gpio0drv[0]	pup0	gpio0[4]	gpio0[3]	gpio0[2]	gpio0[1]	gpio0[0]	00h
0C	R/W	GPIO1 Configuration	gpio1drv[1]	gpio1drv[0]	pup1	gpio1[4]	gpio1[3]	gpio1[2]	gpio1[1]	gpio1[0]	00h
0D	R/W	GPIO2 Configuration	gpio2drv[1]	gpio2drv[0]	pup2	gpio2[4]	gpio2[3]	gpio2[2]	gpio2[1]	gpio2[0]	00h
0E	R/W	I/O Port Configuration		extitst[2]	extitst[1]	extitst[0]	itsdo	dio2	dio1	dio0	00h

The GPIO settings for GPIO1 and GPIO2 are the same as for GPIO0 with the exception of the 00000 default setting. The default settings for each GPIO are listed below:

GPIO	00000—Default Setting
GPIO0	POR
GPIO1	POR Inverted
GPIO2	Microcontroller Clock

For a complete list of the available GPIO's see “AN440: EZRadioPRO Detailed Register Descriptions”.

The GPIO drive strength may be adjusted with the gpioXdrv[1:0] bits. Setting a higher value will increase the drive strength and current capability of the GPIO by changing the driver size. Special care should be taken in setting the drive strength and loading on GPIO2 when the microcontroller clock is used. Excess loading or inadequate drive may contribute to increased spurious emissions.

Pin 6, ANT may be used as an alternate to control a TR switch. Pin 6 is a hardwired version of GPIO setting 11000, Antenna 2 Switch used for antenna diversity. It can be manually controlled by the antdiv[2:0] bits in register 08h if antenna diversity is not used. See AN440, register 08h for more details.

8.9. Antenna Diversity

To mitigate the problem of frequency-selective fading due to multi-path propagation, some transceiver systems use a scheme known as antenna diversity. In this scheme, two antennas are used. Each time the transceiver enters RX mode the receive signal strength from each antenna is evaluated. This evaluation process takes place during the preamble portion of the packet. The antenna with the strongest received signal is then used for the remainder of that RX packet. The same antenna will also be used for the next corresponding TX packet.

This chip fully supports antenna diversity with an integrated antenna diversity control algorithm. The required signals needed to control an external SPDT RF switch (such as PIN diode or GaAs switch) are available on the GPIOx pins. The operation of these GPIO signals is programmable to allow for different antenna diversity architectures and configurations. The antdiv[2:0] bits are found in register 08h “Operating & Function Control 2.” The GPIO pins are capable of sourcing up to 5 mA of current, so it may be used directly to forward-bias a PIN diode if desired.

The antenna diversity algorithm will automatically toggle back and forth between the antennas until the packet starts to arrive. The recommended preamble length for optimal antenna selection is 8 bytes. A special antenna diversity algorithm (antdiv[2:0] = 110 or 111) is included that allows for shorter preamble lengths for beacon mode in TDMA-like systems where the arrival of the packet is synchronous to the receiver enable. The recommended preamble length to obtain optimal antenna selection for synchronous mode is 4 bytes.

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
08	R/W	Operating & Function Control 2	antdiv[2]	antdiv[1]	antdiv[0]	rxmpk	autotx	enldm	ffclrrx	ffclrtx	00h

Table 17. Antenna Diversity Control

antdiv[2:0]	RX/TX State		Non RX/TX State	
	GPIO Ant1	GPIO Ant2	GPIO Ant1	GPIO Ant2
000	0	1	0	0
001	1	0	0	0
010	0	1	1	1
011	1	0	1	1
100	Antenna Diversity Algorithm		0	0
101	Antenna Diversity Algorithm		1	1
110	Antenna Diversity Algorithm in Beacon Mode		0	0
111	Antenna Diversity Algorithm in Beacon Mode		1	1

8.10. RSSI and Clear Channel Assessment

Received signal strength indicator (RSSI) is an estimate of the signal strength in the channel to which the receiver is tuned. The RSSI value can be read from an 8-bit register with 0.5 dB resolution per bit. Figure 31 demonstrates the relationship between input power level and RSSI value. The absolute value of the RSSI will change slightly depending on the modem settings. The RSSI may be read at anytime, but an incorrect error may rarely occur. The RSSI value may be incorrect if read during the update period. The update period is approximately 10 ns every 4 Tb. For 10 kbps, this would result in a 1 in 40,000 probability that the RSSI may be read incorrectly. This probability is extremely low, but to avoid this, one of the following options is recommended: majority polling, reading the RSSI value within 1 Tb of the RSSI interrupt, or using the RSSI threshold described in the next paragraph for Clear Channel Assessment (CCA).

Add	R/W	Function/Description	D7	D6	D5	D4	D3	D2	D1	D0	POR Def.
26	R	Received Signal Strength Indicator	rssi[7]	rssi[6]	rssi[5]	rssi[4]	rssi[3]	rssi[2]	rssi[1]	rssi[0]	—
27	R/W	RSSI Threshold for Clear Channel Indicator	rssith[7]	rssith[6]	rssith[5]	rssith[4]	rssith[3]	rssith[2]	rssith[1]	rssith[0]	00h

For CCA, threshold is programmed into rssith[7:0] in "Register 27h. RSSI Threshold for Clear Channel Indicator." After the RSSI is evaluated in the preamble, a decision is made if the signal strength on this channel is above or below the threshold. If the signal strength is above the programmed threshold then the RSSI status bit, irssi, in "Register 04h. Interrupt/Status 2" will be set to 1. The RSSI status can also be routed to a GPIO line by configuring the GPIO configuration register to GPIOx[3:0] = 1110.

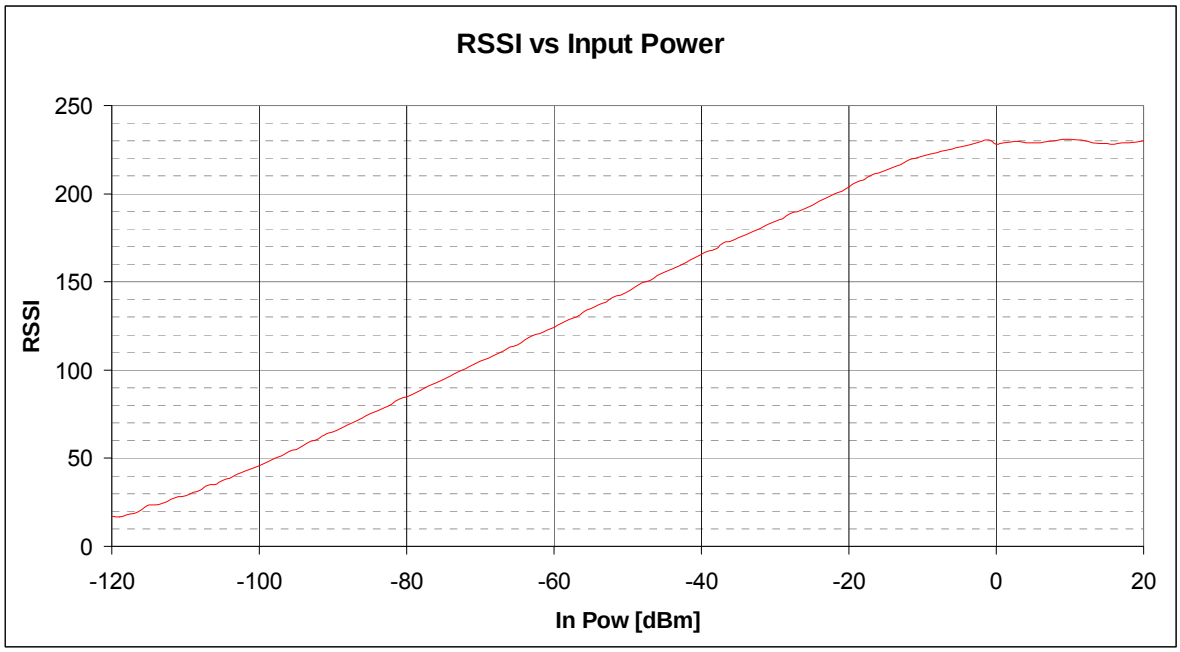


Figure 31. RSSI Value vs. Input Power

9. Reference Design

Reference designs are available at www.silabs.com for many common applications which include recommended schematics, BOM, and layout. TX matching component values for the different frequency bands can be found in the application notes “AN435: Si4032/4432 PA Matching” and “AN436: Si4030/4031/4430/4431 PA Matching.” RX matching component values for different frequency bands can be found in “AN427: EZRadioPRO Si433x and Si443x RX LNA Matching.”

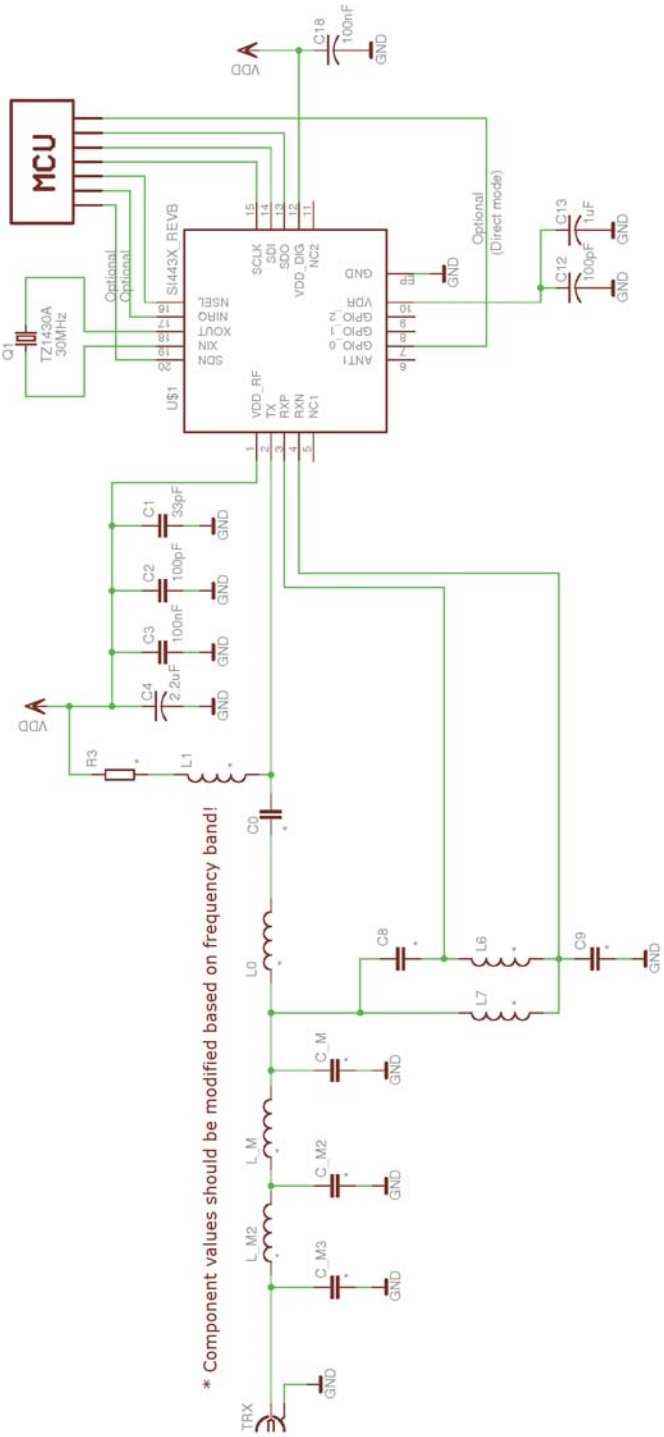


Figure 32. TX/RX Direct-Tie Reference Design Schematic

10. Application Notes and Reference Designs

A comprehensive set of application notes and reference designs are available to assist with the development of a radio system. A partial list of applications notes is given below.

For the complete list of application notes, latest reference designs and demos visit the Silicon Labs website.

- AN361: Wireless MBUS Implementation using EZRadioPRO Devices
- AN379: Antenna Diversity with EZRadioPRO
- AN414: EZRadioPRO Layout Design Guide
- AN415: EZRadioPRO Programming Guide
- AN417: Si4x3x Family Crystal Oscillators
- AN419: ARIB STD-T67 Narrow-Band 426/429 MHz Measured on the Si4431-A0
- AN427: EZRadioPRO Si433x and Si443x RX LNA Matching
- AN429: Using the DC-DC Converter on the F9xx Series MCU for Single Battery Operation with the EZRadioPRO RF Devices
- AN432: RX BER Measurement on EZRadioPRO with a Looped PN Sequence
- AN435: Si4032/4432 PA Matching
- AN436: Si4030/4031/4430/4431 PA Matching
- AN437: 915 MHz Measurement Results and FCC Compliance
- AN439: EZRadioPRO Quick Start Guide
- AN440: Si4430/31/32 Register Descriptions
- AN445: Si4431 RF Performance and ETSI Compliance Test Results
- AN451: Wireless M-BUS Software Implementation
- AN459: 950 MHz Measurement Results and ARIB Compliance
- AN460: 470 MHz Measurement Results for China
- AN463: Support for Non-Standard Packet Structures and RAW Mode
- AN466: Si4030/31/32 Register Descriptions
- AN467: Si4330 Register Descriptions
- AN514: Using the EZLink Reference Design to Create a Two-Channel PWM Motor Control Circuit
- AN539: EZMacPRO Overview

11. Customer Support

Technical support for the complete family of Silicon Labs wireless products is available by accessing the wireless section of the Silicon Labs' website at www.silabs.com/wireless. For answers to common questions please visit the wireless knowledge base at www.silabs.com/support/knowledgebase.

12. Register Table and Descriptions

Table 18. Register Descriptions

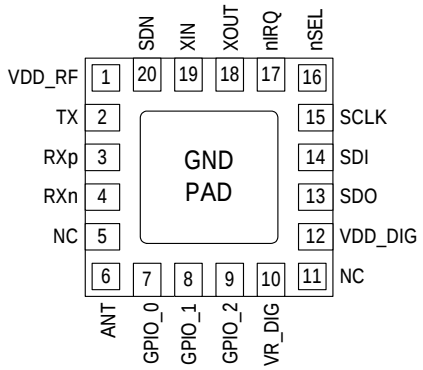
Add	R/W	Function/Desc	Data								POR Default
			D7	D6	D5	D4	D3	D2	D1	D0	
00	R	Device Type	0	0	0	dt[4]	dt[3]	dt[2]	dt[1]	dt[0]	00111
01	R	Device Version	0	0	0	vc[4]	vc[3]	vc[2]	vc[1]	vc[0]	06h
02	R	Device Status	ffovfl	ffunfl	rxffem	headerr	reserved	reserved	cps[1]	cps[0]	—
03	R	Interrupt Status 1	ifferr	itxffafull	itxffaem	irxffafull	iext	ipksent	ipkvalid	icrcerror	—
04	R	Interrupt Status 2	iswdet	ipreaval	ipreainval	irssi	iwut	ilbd	ichiprdy	ipor	—
05	R/W	Interrupt Enable 1	enfferr	entxffafull	entxffaem	enrxffafull	enext	enpksent	enpkvalid	encrcerror	00h
06	R/W	Interrupt Enable 2	enswdet	enpreaval	enpreainval	enrssi	enwut	enlbd	enchiprdy	enpor	03h
07	R/W	Operating & Function Control 1	swres	enlbd	enwt	x32ksel	txon	rxon	pllon	xton	01h
08	R/W	Operating & Function Control 2	antdiv[2]	antdiv[1]	antdiv[0]	rxmpk	autotx	enldm	ffclrrx	ffclrtx	00h
09	R/W	Crystal Oscillator Load Capacitance	xtalshft	xlc[6]	xlc[5]	xlc[4]	xlc[3]	xlc[2]	xlc[1]	xlc[0]	7Fh
0A	R/W	Microcontroller Output Clock	Reserved	Reserved	clkt[1]	clkt[0]	enlfc	mclk[2]	mclk[1]	mclk[0]	06h
0B	R/W	GPIO0 Configuration	gpio0drv[1]	gpio0drv[0]	pup0	gpio0[4]	gpio0[3]	gpio0[2]	gpio0[1]	gpio0[0]	00h
0C	R/W	GPIO1 Configuration	gpio1drv[1]	gpio1drv[0]	pup1	gpio1[4]	gpio1[3]	gpio1[2]	gpio1[1]	gpio1[0]	00h
0D	R/W	GPIO2 Configuration	gpio2drv[1]	gpio2drv[0]	pup2	gpio2[4]	gpio2[3]	gpio2[2]	gpio2[1]	gpio2[0]	00h
0E	R/W	I/O Port Configuration	Reserved	extitst[2]	extitst[1]	extitst[0]	itsdo	dio2	dio1	dio0	00h
0F	R/W	ADC Configuration	adcstart/*adc-done*	adcsel[2]	adcsel[1]	adcsel[0]	adcref[1]	adcref[0]	adcgain[1]	adcgain[0]	00h
10	R/W	ADC Sensor Amplifier Offset	Reserved	Reserved	Reserved	Reserved	adcoffs[3]	adcoffs[2]	adcoffs[1]	adcoffs[0]	00h
11	R	ADC Value	adc[7]	adc[6]	adc[5]	adc[4]	adc[3]	adc[2]	adc[1]	adc[0]	—
12	R/W	Temperature Sensor Control	tsrange[1]	tsrange[0]	entsoffs	entstrim	tstrim[3]	tstrim[2]	tstrim[1]	tstrim[0]	20h
13	R/W	Temperature Value Offset	tvoffs[7]	tvoffs[6]	tvoffs[5]	tvoffs[4]	tvoffs[3]	tvoffs[2]	tvoffs[1]	tvoffs[0]	00h
14	R/W	Wake-Up Timer Period 1	Reserved	Reserved	Reserved	wtr[4]	wtr[3]	wtr[2]	wtr[1]	wtr[0]	03h
15	R/W	Wake-Up Timer Period 2	wtm[15]	wtm[14]	wtm[13]	wtm[12]	wtm[11]	wtm[10]	wtm[9]	wtm[8]	00h
16	R/W	Wake-Up Timer Period 3	wtm[7]	wtm[6]	wtm[5]	wtm[4]	wtm[3]	wtm[2]	wtm[1]	wtm[0]	01h
17	R	Wake-Up Timer Value 1	wtv[15]	wtv[14]	wtv[13]	wtv[12]	wtv[11]	wtv[10]	wtv[9]	wtv[8]	—
18	R	Wake-Up Timer Value 2	wtv[7]	wtv[6]	wtv[5]	wtv[4]	wtv[3]	wtv[2]	wtv[1]	wtv[0]	—
19	R/W	Low-Duty Cycle Mode Duration	ldc[7]	ldc[6]	ldc[5]	ldc[4]	ldc[3]	ldc[2]	ldc[1]	ldc[0]	00h
1A	R/W	Low Battery Detector Threshold	Reserved	Reserved	Reserved	lbdt[4]	lbdt[3]	lbdt[2]	lbdt[1]	lbdt[0]	14h
1B	R	Battery Voltage Level	0	0	0	vbat[4]	vbat[3]	vbat[2]	vbat[1]	vbat[0]	—
1C	R/W	IF Filter Bandwidth	dwn3_bypass	ndec[2]	ndec[1]	ndec[0]	filset[3]	filset[2]	filset[1]	filset[0]	01h
1D	R/W	AFC Loop Gearshift Override	afcbd	enafc	afcgearh[2]	afcgearh[1]	afcgearh[0]	1p5 bypass	matap	ph0size	40h
1E	R/W	AFC Timing Control	swait_timer[1]	swait_timer[0]	shwait[2]	shwait[1]	shwait[0]	anwait[2]	anwait[1]	anwait[0]	0Ah
1F	R/W	Clock Recovery Gearshift Override	Reserved	Reserved	crfast[2]	crfast[1]	crfast[0]	crslow[2]	crslow[1]	crslow[0]	03h
20	R/W	Clock Recovery Oversampling Ratio	rxosr[7]	rxosr[6]	rxosr[5]	rxosr[4]	rxosr[3]	rxosr[2]	rxosr[1]	rxosr[0]	64h
21	R/W	Clock Recovery Offset 2	rxosr[10]	rxosr[9]	rxosr[8]	stallctrl	ncoff[19]	ncoff[18]	ncoff[17]	ncoff[16]	01h
22	R/W	Clock Recovery Offset 1	ncoff[15]	ncoff[14]	ncoff[13]	ncoff[12]	ncoff[11]	ncoff[10]	ncoff[9]	ncoff[8]	47h
23	R/W	Clock Recovery Offset 0	ncoff[7]	ncoff[6]	ncoff[5]	ncoff[4]	ncoff[3]	ncoff[2]	ncoff[1]	ncoff[0]	AEh
24	R/W	Clock Recovery Timing Loop Gain 1	Reserved	Reserved	Reserved	rxncocomp	crgain2x	crgain[10]	crgain[9]	crgain[8]	02h
25	R/W	Clock Recovery Timing Loop Gain 0	crgain[7]	crgain[6]	crgain[5]	crgain[4]	crgain[3]	crgain[2]	crgain[1]	crgain[0]	8Fh
26	R	Received Signal Strength Indicator	rssi[7]	rssi[6]	rssi[5]	rssi[4]	rssi[3]	rssi[2]	rssi[1]	rssi[0]	—
27	R/W	RSSI Threshold for Clear Channel Indicator	rssith[7]	rssith[6]	rssith[5]	rssith[4]	rssith[3]	rssith[2]	rssith[1]	rssith[0]	1Eh
28	R	Antenna Diversity Register 1	adrssi1[7]	adrssia[6]	adrssia[5]	adrssia[4]	adrssia[3]	adrssia[2]	adrssia[1]	adrssia[0]	—
29	R	Antenna Diversity Register 2	adrssib[7]	adrssib[6]	adrssib[5]	adrssib[4]	adrssib[3]	adrssib[2]	adrssib[1]	adrssib[0]	—
2A	R/W	AFC Limiter	Afclim[7]	Afclim[6]	Afclim[5]	Afclim[4]	Afclim[3]	Afclim[2]	Afclim[1]	Afclim[0]	00h
2B	R	AFC Correction Read	afc_corr[9]	afc_corr[8]	afc_corr[7]	afc_corr[6]	afc_corr[5]	afc_corr[4]	afc_corr[3]	afc_corr[2]	00h
2C	R/W	OOK Counter Value 1	afc_corr[9]	afc_corr[9]	ookfrzen	peakdeten	madeten	ookcnt[10]	ookcnt[9]	ookcnt[8]	18h
2D	R/W	OOK Counter Value 2	ookcnt[7]	ookcnt[6]	ookcnt[5]	ookcnt[4]	ookcnt[3]	ookcnt[2]	ookcnt[1]	ookcnt[0]	BCh
2E	R/W	Slicer Peak Hold	Reserved	attack[2]	attack[1]	attack[0]	decay[3]	decay[2]	decay[1]	decay[0]	26h
2F	Reserved										
30	R/W	Data Access Control	enpacrx	lsbfrst	crcdonly	skip2ph	enpactx	encrc	crc[1]	crc[0]	8Dh

Table 18. Register Descriptions (Continued)

Add	R/W	Function/Desc	Data								POR Default
			D7	D6	D5	D4	D3	D2	D1	D0	
31	R	EzMAC status	0	rxcrc1	pksrch	pkrx	pkvalid	crcerror	pktx	pksent	—
32	R/W	Header Control 1	bcen[3:0]				hdch[3:0]				0Ch
33	R/W	Header Control 2	skipsyn	hdlen[2]	hdlen[1]	hdlen[0]	fixpklen	synclen[1]	synclen[0]	prealen[8]	22h
34	R/W	Preamble Length	prealen[7]	prealen[6]	prealen[5]	prealen[4]	prealen[3]	prealen[2]	prealen[1]	prealen[0]	08h
35	R/W	Preamble Detection Control	preath[4]	preath[3]	preath[2]	preath[1]	preath[0]	rssi_off[2]	rssi_off[1]	rssi_off[0]	2Ah
36	R/W	Sync Word 3	sync[31]	sync[30]	sync[29]	sync[28]	sync[27]	sync[26]	sync[25]	sync[24]	2Dh
37	R/W	Sync Word 2	sync[23]	sync[22]	sync[21]	sync[20]	sync[19]	sync[18]	sync[17]	sync[16]	D4h
38	R/W	Sync Word 1	sync[15]	sync[14]	sync[13]	sync[12]	sync[11]	sync[10]	sync[9]	sync[8]	00h
39	R/W	Sync Word 0	sync[7]	sync[6]	sync[5]	sync[4]	sync[3]	sync[2]	sync[1]	sync[0]	00h
3A	R/W	Transmit Header 3	txhd[31]	txhd[30]	txhd[29]	txhd[28]	txhd[27]	txhd[26]	txhd[25]	txhd[24]	00h
3B	R/W	Transmit Header 2	txhd[23]	txhd[22]	txhd[21]	txhd[20]	txhd[19]	txhd[18]	txhd[17]	txhd[16]	00h
3C	R/W	Transmit Header 1	txhd[15]	txhd[14]	txhd[13]	txhd[12]	txhd[11]	txhd[10]	txhd[9]	txhd[8]	00h
3D	R/W	Transmit Header 0	txhd[7]	txhd[6]	txhd[5]	txhd[4]	txhd[3]	txhd[2]	txhd[1]	txhd[0]	00h
3E	R/W	Transmit Packet Length	pklen[7]	pklen[6]	pklen[5]	pklen[4]	pklen[3]	pklen[2]	pklen[1]	pklen[0]	00h
3F	R/W	Check Header 3	chhd[31]	chhd[30]	chhd[29]	chhd[28]	chhd[27]	chhd[26]	chhd[25]	chhd[24]	00h
40	R/W	Check Header 2	chhd[23]	chhd[22]	chhd[21]	chhd[20]	chhd[19]	chhd[18]	chhd[17]	chhd[16]	00h
41	R/W	Check Header 1	chhd[15]	chhd[14]	chhd[13]	chhd[12]	chhd[11]	chhd[10]	chhd[9]	chhd[8]	00h
42	R/W	Check Header 0	chhd[7]	chhd[6]	chhd[5]	chhd[4]	chhd[3]	chhd[2]	chhd[1]	chhd[0]	00h
43	R/W	Header Enable 3	hden[31]	hden[30]	hden[29]	hden[28]	hden[27]	hden[26]	hden[25]	hden[24]	FFh
44	R/W	Header Enable 2	hden[23]	hden[22]	hden[21]	hden[20]	hden[19]	hden[18]	hden[17]	hden[16]	FFh
45	R/W	Header Enable 1	hden[15]	hden[14]	hden[13]	hden[12]	hden[11]	hden[10]	hden[9]	hden[8]	FFh
46	R/W	Header Enable 0	hden[7]	hden[6]	hden[5]	hden[4]	hden[3]	hden[2]	hden[1]	hden[0]	FFh
47	R	Received Header 3	rxhd[31]	rxhd[30]	rxhd[29]	rxhd[28]	rxhd[27]	rxhd[26]	rxhd[25]	rxhd[24]	—
48	R	Received Header 2	rxhd[23]	rxhd[22]	rxhd[21]	rxhd[20]	rxhd[19]	rxhd[18]	rxhd[17]	rxhd[16]	—
49	R	Received Header 1	rxhd[15]	rxhd[14]	rxhd[13]	rxhd[12]	rxhd[11]	rxhd[10]	rxhd[9]	rxhd[8]	—
4A	R	Received Header 0	rxhd[7]	rxhd[6]	rxhd[5]	rxhd[4]	rxhd[3]	rxhd[2]	rxhd[1]	rxhd[0]	—
4B	R	Received Packet Length	rxplen[7]	rxplen[6]	rxplen[5]	rxplen[4]	rxplen[3]	rxplen[2]	rxplen[1]	rxplen[0]	—
4C-4E	Reserved										
4F	R/W	ADC8 Control	Reserved	Reserved	adc8[5]	adc8[4]	adc8[3]	adc8[2]	adc8[1]	adc8[0]	10h
50-5F	Reserved										
60	R/W	Channel Filter Coefficient Address	Inv_pre_th[3]	Inv_pre_th[2]	Inv_pre_th[1]	Inv_pre_th[0]	chfiladd[3]	chfiladd[2]	chfiladd[1]	chfiladd[0]	00h
61	Reserved										
62	R/W	Crystal Oscillator/Control Test	pwst[2]	pwst[1]	pwst[0]	clkhyst	enbias2x	enamp2x	bufovr	enbuf	24h
63-68	Reserved										
69	R/W	AGC Override 1	Reserved	sgi	agcen	lnagain	pga3	pga2	pga1	pga0	20h
6A-6C	Reserved										
6D	R/W	TX Power	Reserved	Reserved	Reserved	Reserved	lna_sw	txpow[2]	txpow[1]	txpow[0]	18h
6E	R/W	TX Data Rate 1	txdr[15]	txdr[14]	txdr[13]	txdr[12]	txdr[11]	txdr[10]	txdr[9]	txdr[8]	0Ah
6F	R/W	TX Data Rate 0	txdr[7]	txdr[6]	txdr[5]	txdr[4]	txdr[3]	txdr[2]	txdr[1]	txdr[0]	3Dh
70	R/W	Modulation Mode Control 1	Reserved	Reserved	txdtrtscale	enphpwdn	manppol	enmaninv	enmanch	enwhite	0Ch
71	R/W	Modulation Mode Control 2	trclk[1]	trclk[0]	dtmod[1]	dtmod[0]	eninv	fd[8]	modtyp[1]	modtyp[0]	00h
72	R/W	Frequency Deviation	fd[7]	fd[6]	fd[5]	fd[4]	fd[3]	fd[2]	fd[1]	fd[0]	20h
73	R/W	Frequency Offset 1	fo[7]	fo[6]	fo[5]	fo[4]	fo[3]	fo[2]	fo[1]	fo[0]	00h
74	R/W	Frequency Offset 2	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	fo[9]	fo[8]	00h
75	R/W	Frequency Band Select	Reserved	sbsel	hbsel	fb[4]	fb[3]	fb[2]	fb[1]	fb[0]	75h
76	R/W	Nominal Carrier Frequency 1	fc[15]	fc[14]	fc[13]	fc[12]	fc[11]	fc[10]	fc[9]	fc[8]	BBh
77	R/W	Nominal Carrier Frequency 0	fc[7]	fc[6]	fc[5]	fc[4]	fc[3]	fc[2]	fc[1]	fc[0]	80h
78	Reserved										
79	R/W	Frequency Hopping Channel Select	fhch[7]	fhch[6]	fhch[5]	fhch[4]	fhch[3]	fhch[2]	fhch[1]	fhch[0]	00h
7A	R/W	Frequency Hopping Step Size	fhs[7]	fhs[6]	fhs[5]	fhs[4]	fhs[3]	fhs[2]	fhs[1]	fhs[0]	00h
7B	Reserved										
7C	R/W	TX FIFO Control 1	Reserved	Reserved	txafthr[5]	txafthr[4]	txafthr[3]	txafthr[2]	txafthr[1]	txafthr[0]	37h
7D	R/W	TX FIFO Control 2	Reserved	Reserved	txaethr[5]	txaethr[4]	txaethr[3]	txaethr[2]	txaethr[1]	txaethr[0]	04h
7E	R/W	RX FIFO Control	Reserved	Reserved	rxafthr[5]	rxafthr[4]	rxafthr[3]	rxafthr[2]	rxafthr[1]	rxafthr[0]	37h
7F	R/W	FIFO Access	fifod[7]	fifod[6]	fifod[5]	fifod[4]	fifod[3]	fifod[2]	fifod[1]	fifod[0]	—

Note: Detailed register descriptions are available in “AN440: EZRadioPRO Detailed Register Descriptions.”

13. Pin Descriptions: Si4430/31/32



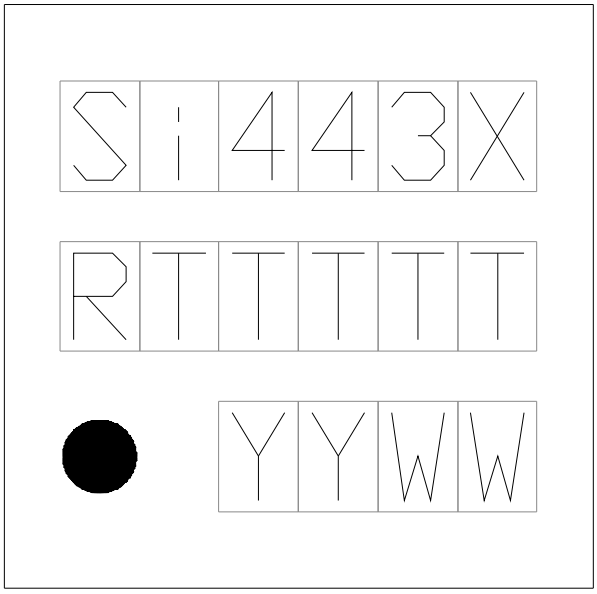
Pin	Pin Name	I/O	Description
1	VDD_RF	VDD	+1.8 to +3.6 V supply voltage input to all analog +1.7 V regulators. The recommended V_{DD} supply voltage is +3.3 V.
2	TX	O	Transmit output pin. The PA output is an open-drain connection so the L-C match must supply VDD (+3.3 VDC nominal) to this pin.
3	RXp	I	Differential RF input pins of the LNA. See application schematic for example matching network.
4	RXn	I	
5	NC	—	No Connect. Not connected internally to any circuitry.
6	ANT	O	Extra antenna or TR switch control to be used if more GPIO are required. Pin is a hardwired version of GPIO setting 11000, Antenna 2 and can be manually controlled by the antdiv[2:0] bits in register 08h. See register description of 08h.
7	GPIO_0	I/O	General Purpose Digital I/O that may be configured through the registers to perform various functions including: Microcontroller Clock Output, FIFO status, POR, Wake-Up timer, Low Battery Detect, TRSW, AntDiversity control, etc. See the SPI GPIO Configuration Registers, Address 0Bh, 0Ch, and 0Dh for more information.
8	GPIO_1	I/O	
9	GPIO_2	I/O	
10	VR_DIG	O	Regulated Output Voltage of the Digital 1.7 V Regulator. A 1 µF decoupling capacitor is required.
11	NC	—	Internally this pin is tied to the paddle of the package. This pin should be left unconnected or connected to GND only.
12	VDD_DIG	VDD	+1.8 to +3.6 V supply voltage input to the Digital +1.7 V Regulator. The recommended V_{DD} supply voltage is +3.3 V.
13	SDO	O	0–V_{DD} V digital output that provides a serial readback function of the internal control registers.
14	SDI	I	Serial Data input. 0–V_{DD} V digital input. This pin provides the serial data stream for the 4-line serial data bus.
15	SCLK	I	Serial Clock input. 0–V_{DD} V digital input. This pin provides the serial data clock function for the 4-line serial data bus. Data is clocked into the Si4430/31/32 on positive edge transitions.
16	nSEL	I	Serial Interface Select input. 0– V_{DD} V digital input. This pin provides the Select/Enable function for the 4-line serial data bus. The signal is also used to signify burst read/write mode.
17	nIRQ	O	General Microcontroller Interrupt Status output. When the Si4430/31/32 exhibits anyone of the Interrupt Events the nIRQ pin will be set low=0. Please see the Control Logic registers section for more information on the Interrupt Events. The Microcontroller can then determine the state of the interrupt by reading a corresponding SPI Interrupt Status Registers, Address 03h and 04h. No external resistor pull-up is required, but it may be desirable if multiple interrupt lines are connected.
18	XOUT	O	Crystal Oscillator Output. Connect to an external 30 MHz crystal or to an external source. If using an external source with no crystal then dc coupling with a nominal 0.8 VDC level is recommended with a minimum amplitude of 700 mVpp.
19	XIN	I	Crystal Oscillator Input. Connect to an external 30 MHz crystal or leave floating when driving with an external source on XOUT..
20	SDN	I	Shutdown input pin. 0–V_{DD} V digital input. SDN should be = 0 in all modes except Shutdown mode. When SDN =1 the chip will be completely shutdown and the contents of the registers will be lost.
PKG	PADDLE_GND	GND	The exposed metal paddle on the bottom of the Si4430/31/32 supplies the RF and circuit ground(s) for the entire chip. It is very important that a good solder connection is made between this exposed metal paddle and the ground plane of the PCB underlying the Si4430/31/32.

14. Ordering Information

Part Number*	Description	Package Type	Operating Temperature
Si4430-B1-FM	ISM EZRadioPRO Transceiver	QFN-20 Pb-free	–40 to 85 °C
Si4431-B1-FM	ISM EZRadioPRO Transceiver	QFN-20 Pb-free	–40 to 85 °C
Si4432-B1-FM	ISM EZRadioPRO Transceiver	QFN-20 Pb-free	–40 to 85 °C
***Note:** Add an “(R)” at the end of the device part number to denote tape and reel option.			

15. Package Markings (Top Marks)

15.1. Si4430/31/32 Top Mark



15.2. Top Mark Explanation

Mark Method:	YAG Laser	
Line 1 Marking:	X = Part Number	0 = Si4430 1 = Si4431 2 = Si4432
Line 2 Marking:	R = Die Revision	B = Revision B1
	TTTTT = Internal Code	Internal tracking code.
Line 3 Marking:	YY= Year WW = Workweek	Assigned by the Assembly House. Corresponds to the last significant digit of the year and workweek of the mold date.

16. Package Outline: Si4430/31/32

Figure 33 illustrates the package details for the Si4430/31/32. Table 19 lists the values for the dimensions shown in the illustration.

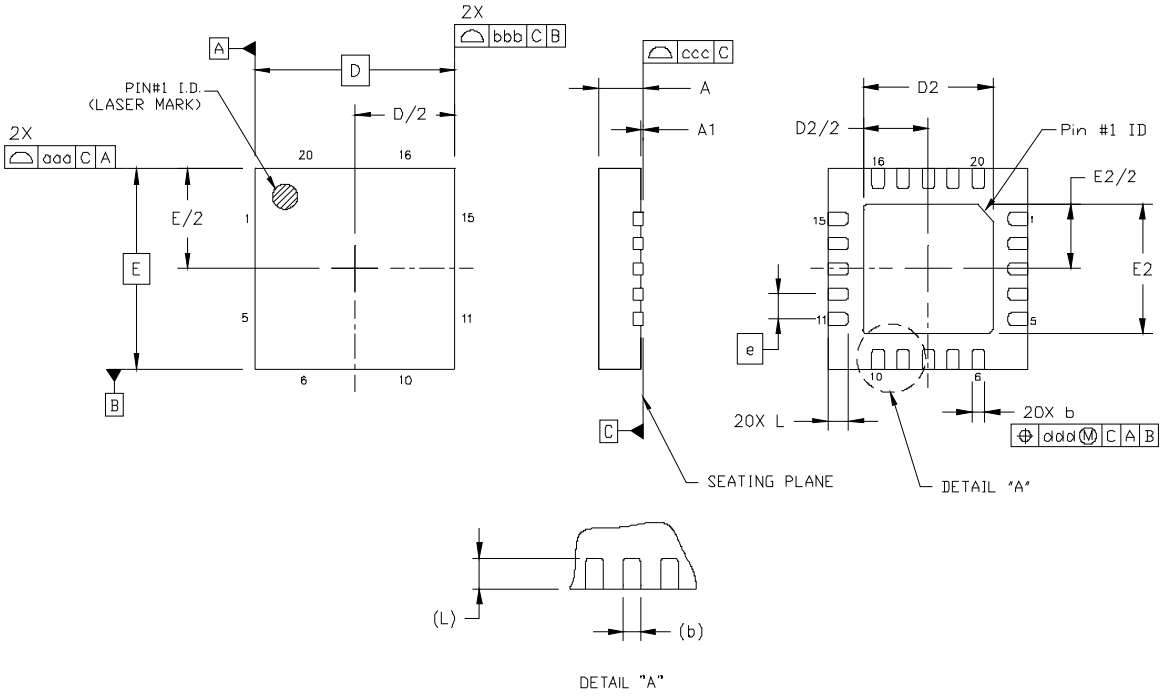


Figure 33. 20-Pin Quad Flat No-Lead (QFN)

Table 19. Package Dimensions

Symbol	Millimeters		
	Min	Nom	Max
A	0.80	0.85	0.90
A1	0.00	0.02	0.05
b	0.18	0.25	0.30
D		4.00 BSC	
D2	2.55	2.60	2.65
e		0.50 BSC	
E		4.00 BSC	
E2	2.50	2.60	2.70
L	0.30	0.40	0.50
aaa	—	—	0.10
bbb	—	—	0.10
ccc	—	—	0.08
ddd	—	—	0.10
eee	—	—	0.10

Notes:

1. All dimensions are shown in millimeters (mm) unless otherwise noted.
2. Dimensioning and tolerancing per ANSI Y14.5M-1994.
3. This drawing conforms to the JEDEC Solid State Outline MO-220, Variation VGGD-8.
4. Recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for Small Body Components.

17. PCB Land Pattern: Si4430/31/32

Figure 34 illustrates the PCB land pattern details for the Si4430/31/32. Table 20 lists the values for the dimensions shown in the illustration.

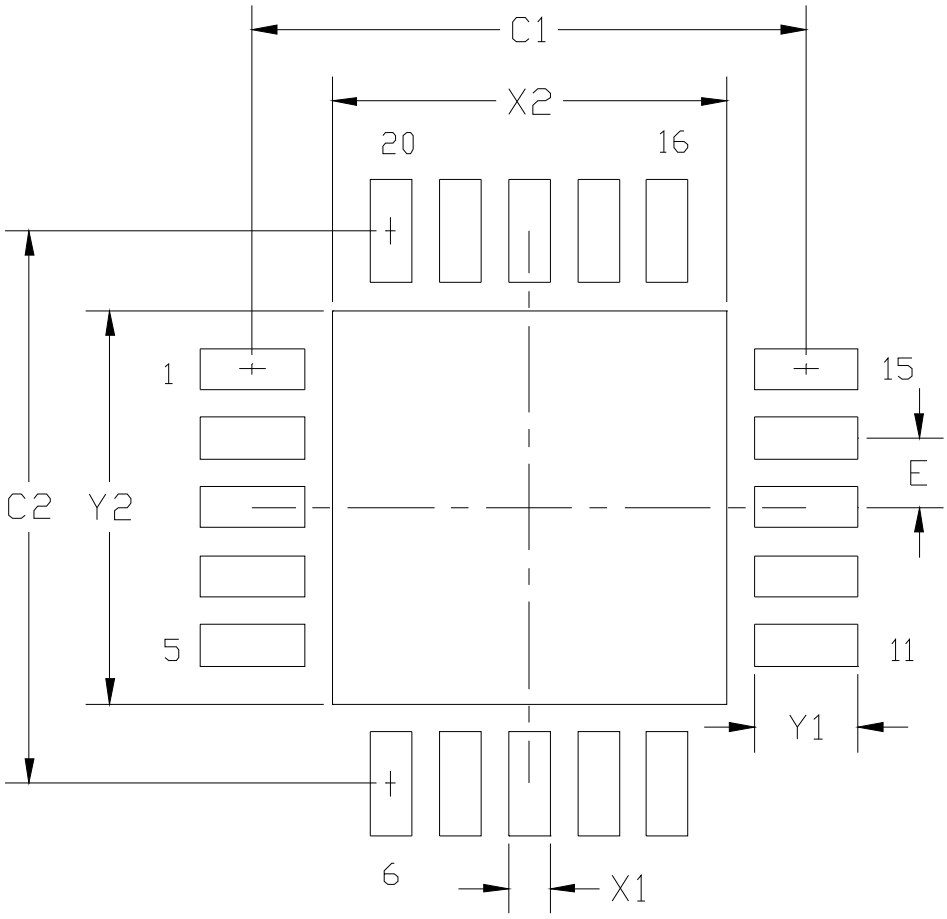


Figure 34. PCB Land Pattern

Table 20. PCB Land Pattern Dimensions

Symbol	Millimeters	
	Min	Max
C1	3.90	4.00
C2	3.90	4.00
E	0.50 REF	
X1	0.20	0.30
X2	2.65	2.75
Y1	0.65	0.75
Y2	2.65	2.75

Notes: General

1. All dimensions shown are in millimeters (mm) unless otherwise noted.
2. This land pattern design is based on IPC-7351 guidelines.

Note: Solder Mask Design

1. All metal pads are to be non-solder mask defined (NSMD). Clearance between the solder mask and the metal pad is to be 60 µm minimum, all the way around the pad.

Notes: Stencil Design

1. A stainless steel, laser-cut and electro-polished stencil with trapezoidal walls should be used to assure good solder paste release.
2. The stencil thickness should be 0.125 mm (5 mils).
3. The ratio of stencil aperture to land pad size should be 1:1 for the perimeter pads.
4. A 2x2 array of 1.10 x 1.10 mm openings on 1.30 mm pitch should be used for the center ground pad.

Notes: Card Assembly

1. A No-Clean, Type-3 solder paste is recommended.
2. The recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for small body components.

DOCUMENT CHANGE LIST

Revision 0.4 to Revision 1.0

- Combined 4430/4431/4432 into single data sheet.
- Added Max Shutdown and Standby Currents and adjusted typical values.
- Updated TX currents.
- Increased datarate to 256 kbps.
- Updated Table 11 on page 20.
- Revised "7. RX Modem Configuration" on page 49.
- Added Sync and Header sections for packet handler description
- Updated descriptions on FIFO and Direct Modes
- Changed pin 5 to NC and pin 6 to Ant1
- Updated "9. Reference Design" on page 62.
- Moved Detailed Register Descriptions to Application Note (AN440)
- Moved Measurement Results to Application Note (AN438)
- Replaced Applications Section with links to App Notes

Revision 1.0 to Revision 1.1

- Updated pin 6, ANT1 to ANT.
- Changed error in TX Datarate formula, "3.5.7. TX Data Rate Generator" on page 31.
- Updated "6.1. RX and TX FIFOs" on page 41 regarding the operation at the end of TX FIFO mode.
- Updated description of general purpose ADC, "8.3. General Purpose ADC" on page 52.
- Added paragraph to "8.6. Wake-Up Timer and 32 kHz Clock Source" on page 56 for how 32 kHz XTAL accuracy is determined.
- Added paragraph to "8.8. GPIO Configuration" on page 59 to describe how to control the ANT pin.
- Deleted 100 ppm 32 kHz XTAL accuracy specification.
- Added new specification for 32k RC start-up.
- Updated 32 kHz RC accuracy.
- Updated preamble pattern to 010101 from 101010.
- Deleted app notes which are not published.
- Deleted tape and real quantity.

NOTES:

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