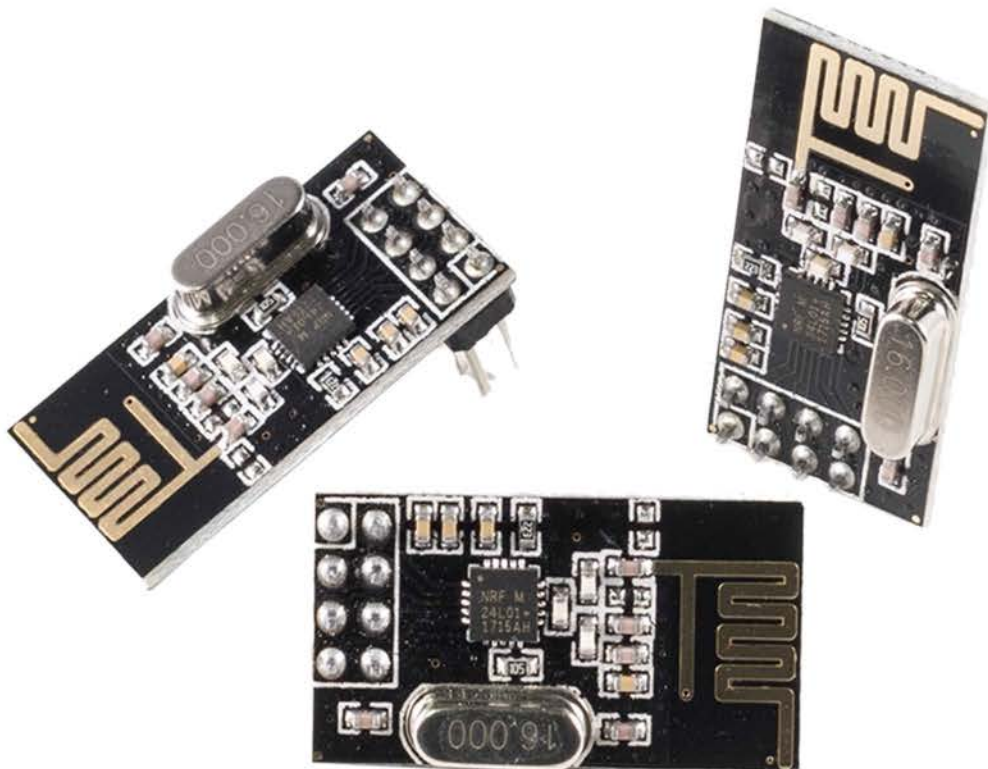


NRF24L01 mit 2,4 GHz Datenblatt



Contents:

- 1. Features**
- 2. Pin Information**
- 3. Absolute Maximum Ratings**
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1. Features

The nRF24L01+ is a single chip 2.4GHz transceiver with an embedded baseband protocol engine (Enhanced ShockBurst™), suitable for ultra low power wireless applications.

The nRF24L01+ is designed for operation in the world wide ISM frequency band at 2.400 - 2.4835GHz. To design a radio system with the nRF24L01+, you simply need an MCU (microcontroller) and a few external passive components.

You can operate and configure the nRF24L01+ through a Serial Peripheral Interface (SPI).

The register map, which is accessible through the SPI, contains all configuration registers in the nRF24L01+ and is accessible in all operation modes of the chip.

The embedded baseband protocol engine (Enhanced ShockBurst™) is based on packet communication and supports various modes from manual operation to advanced autonomous protocol operation. Internal FIFOs ensure a smooth data flow between the radio front end and the system's MCU. Enhanced ShockBurst™ reduces system cost by handling all the high speed link layer operations. The radio front end uses GFSK modulation. It has user configurable parameters like frequency channel, output power and air data rate. nRF24L01+ supports an air data rate of 250 kbps, 1 Mbps and 2Mbps. The high air data rate combined with two power saving modes make the nRF24L01+ very suitable for ultra low power designs.

nRF24L01+ is drop-in compatible with nRF24L01 and on-air compatible with nRF2401A, nRF2402, nRF24E1 and nRF24E2. Intermodulation and wideband blocking values in nRF24L01+ are much improved in comparison to the nRF24L01 and the addition of internal filtering to nRF24L01+ has improved the margins for meeting RF regulatory standards. Internal voltage regulators ensure a high Power Supply Rejection Ratio (PSRR) and a wide power supply range.

1.1 Features

Features of the nRF24L01+ include:

- Radio
 - › Worldwide 2.4GHz ISM band operation
 - › 126 RF channels
 - › Common RX and TX interface
 - › GFSK modulation
 - › 250kbps, 1 and 2Mbps air data rate
 - › 1MHz non-overlapping channel spacing at 1Mbps
 - › 2MHz non-overlapping channel spacing at 2Mbps
- Transmitter
 - › Programmable output power: 0, -6, -12 or -18dBm
 - › 11.3mA at 0dBm output power

1.2 Block diagram

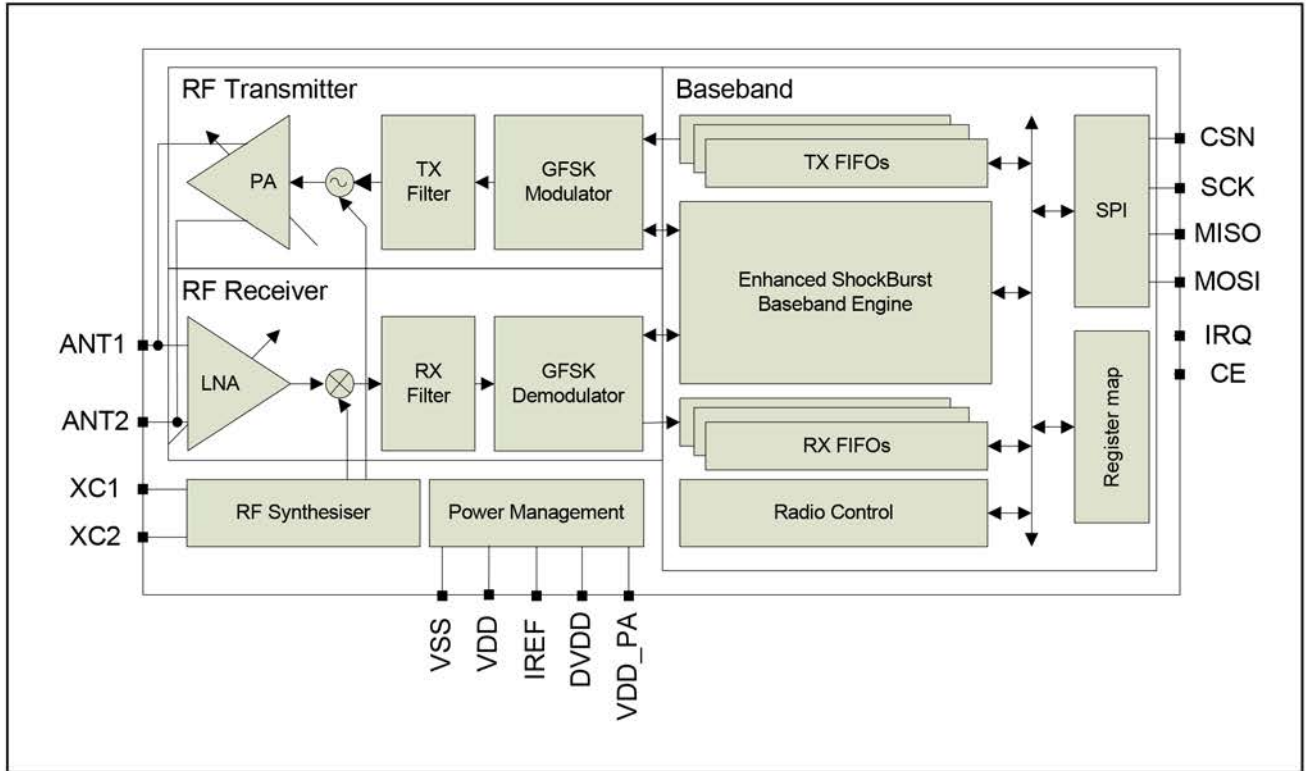


Figure 1. nRF24L01+ block diagram

2. Pin Information

2.1 Pin assignment

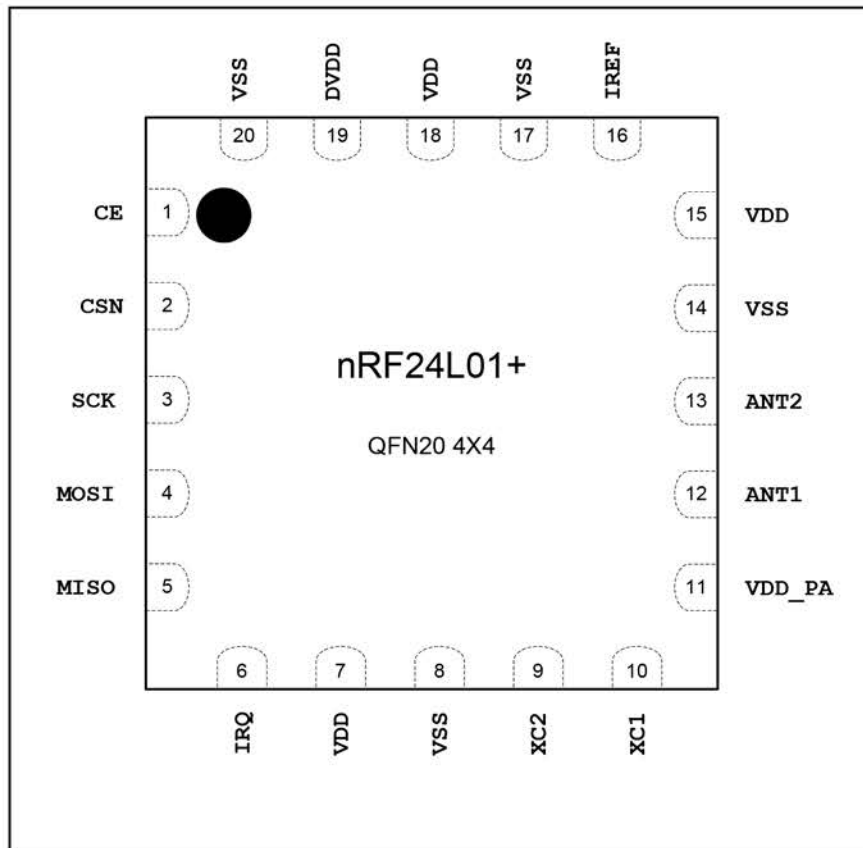


Figure 2. nRF24L01+ pin assignment (top view) for the QFN20 4x4 package

Pin	Name	Pin function	Description
1	CE	Digital Input	Chip Enable Activates RX or TX mode
2	CSN	Digital Input	SPI Chip Select
3	SCK	Digital Input	SPI Clock
4	MOSI	Digital Input	SPI Slave Data Input
5	MISO	Digital Output	SPI Slave Data Output, with tri-state option
6	IRQ	Digital Output	Maskable interrupt pin. Active low
7	VDD	Power	Power Supply (+1.9V - +3.6V DC)
8	VSS	Power	Ground (0V)
9	XC2	Analog Output	Crystal Pin 2
10	XC1	Analog Input	Crystal Pin 1
11	VDD_PA	Power Output	Power Supply Output (+1.8V) for the internal nRF24L01+ Power Amplifier. Must be connected to ANT1 and ANT2 as shown in Figure 29 .
12	ANT1	RF	Antenna interface 1
13	ANT2	RF	Antenna interface 2
14	VSS	Power	Ground (0V)
15	VDD	Power	Power Supply (+1.9V - +3.6V DC)
16	IREF	Analog Input	Reference current. Connect a 22kΩ resistor to ground. See Figure 29 .
17	VSS	Power	Ground (0V)
18	VDD	Power	Power Supply (+1.9V - +3.6V DC)
19	DVDD	Power Output	Internal digital supply output for de-coupling purposes. See Figure 29 .
20	VSS	Power	Ground (0V)

Table 1. nRF24L01+ pin function

3. Absolute maximum ratings

Note: Exceeding one or more of the limiting values may cause permanent damage to nRF24L01+.

Operating conditions	Minimum	Maximum	Units
Supply voltages			
VDD	-0.3	3.6	V
VSS		0	V
Input voltage			
V _I	-0.3	5.25	V
Output voltage			
V _O	VSS to VDD	VSS to VDD	
Total Power Dissipation			
P _D (T _A =85°C)		60	mW
Temperatures			
Operating Temperature	-40	+85	°C
Storage Temperature	-40	+125	°C

Table 2. Absolute maximum ratings

5. Electrical Specifications

Conditions: $V_{DD} = +3V$, $V_{SS} = 0V$, $T_A = -40^{\circ}C$ to $+85^{\circ}C$

5.1 Power consumption

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
	Idle modes					
I_{VDD_PD}	Supply current in power down			900		nA
I_{VDD_ST1}	Supply current in standby-I mode	a		26		μA
I_{VDD_ST2}	Supply current in standby-II mode			320		μA
I_{VDD_SU}	Average current during 1.5ms crystal oscillator startup			400		μA
	Transmit					
I_{VDD_TX0}	Supply current @ 0dBm output power	b		11.3		mA
I_{VDD_TX6}	Supply current @ -6dBm output power	b		9.0		mA
I_{VDD_TX12}	Supply current @ -12dBm output power	b		7.5		mA
I_{VDD_TX18}	Supply current @ -18dBm output power	b		7.0		mA
I_{VDD_AVG}	Average Supply current @ -6dBm output power, ShockBurst™	c		0.12		mA
I_{VDD_TXS}	Average current during TX settling	d		8.0		mA
	Receive					
I_{VDD_2M}	Supply current 2Mbps			13.5		mA
I_{VDD_1M}	Supply current 1Mbps			13.1		mA
I_{VDD_250}	Supply current 250kbps			12.6		mA
I_{VDD_RXS}	Average current during RX settling	e		8.9		mA

a. This current is for a 12pF crystal. Current when using external clock is dependent on signal swing.

b. Antenna load impedance = $15\Omega + j88\Omega$.

c. Antenna load impedance = $15\Omega + j88\Omega$. Average data rate 10kbps and max. payload length packets.

d. Average current consumption during TX startup (130 μs) and when changing mode from RX to TX (130 μs).

e. Average current consumption during RX startup (130 μs) and when changing mode from TX to RX (130 μs).

Table 4. Power consumption

5.2 General RF conditions

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
f _{OP}	Operating frequency	a	2400		2525	MHz
PLL _{res}	PLL Programming resolution			1		MHz
f _{X TAL}	Crystal frequency			16		MHz
Δf ₂₅₀	Frequency deviation @ 250kbps			±160		kHz
Δf _{1M}	Frequency deviation @ 1Mbps			±160		kHz
Δf _{2M}	Frequency deviation @ 2Mbps			±320		kHz
R _{GFSK}	Air Data rate	b	250		2000	kbps
F _{CHANNEL 1M}	Non-overlapping channel spacing @ 250kbps/ 1Mbps	c		1		MHz
F _{CHANNEL 2M}	Non-overlapping channel spacing @ 2Mbps	c		2		MHz

a. Regulatory standards determine the band range you can use.
b. Data rate in each burst on-air
c. The minimum channel spacing is 1MHz

Table 5. General RF conditions

5.3 Transmitter operation

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
P _{RF}	Maximum Output Power	a		0	+4	dBm
P _{RFC}	RF Power Control Range		16	18	20	dB
P _{RFCR}	RF Power Accuracy				±4	dB
P _{BW2}	20dB Bandwidth for Modulated Carrier (2Mbps)			1800	2000	kHz
P _{BW1}	20dB Bandwidth for Modulated Carrier (1Mbps)			900	1000	kHz
P _{BW250}	20dB Bandwidth for Modulated Carrier (250kbps)			700	800	kHz
P _{RF1.2}	1 st Adjacent Channel Transmit Power 2MHz (2Mbps)				-20	dBc
P _{RF2.2}	2 nd Adjacent Channel Transmit Power 4MHz (2Mbps)				-50	dBc
P _{RF1.1}	1 st Adjacent Channel Transmit Power 1MHz (1Mbps)				-20	dBc
P _{RF2.1}	2 nd Adjacent Channel Transmit Power 2MHz (1Mbps)				-45	dBc
P _{RF1.250}	1 st Adjacent Channel Transmit Power 1MHz (250kbps)				-30	dBc
P _{RF2.250}	2 nd Adjacent Channel Transmit Power 2MHz (250kbps)				-45	dBc

a. Antenna load impedance = 15Ω+j88Ω

Table 6. Transmitter operation

5.4 Receiver operation

Datarate	Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
	RX_{max}	Maximum received signal at <0.1% BER			0		dBm
2Mbps	RX_{SENS}	Sensitivity (0.1%BER) @2Mbps			-82		dBm
1Mbps	RX_{SENS}	Sensitivity (0.1%BER) @1Mbps			-85		dBm
250kbps	RX_{SENS}	Sensitivity (0.1%BER) @250kbps			-94		dBm

Table 7. RX Sensitivity

Datarate	Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
2Mbps	C/I_{CO}	C/I Co-channel			7		dBc
	C/I_{1ST}	1 st ACS (Adjacent Channel Selectivity) C/I 2MHz			3		dBc
	C/I_{2ND}	2 nd ACS C/I 4MHz			-17		dBc
	C/I_{3RD}	3 rd ACS C/I 6MHz			-21		dBc
	C/I_{Nth}	N th ACS C/I, $f_i > 12\text{MHz}$			-40		dBc
	C/I_{Nth}	N th ACS C/I, $f_i > 36\text{MHz}$	a		-48		dBc
1Mbps	C/I_{CO}	C/I Co-channel			9		dBc
	C/I_{1ST}	1 st ACS C/I 1MHz			8		dBc
	C/I_{2ND}	2 nd ACS C/I 2MHz			-20		dBc
	C/I_{3RD}	3 rd ACS C/I 3MHz			-30		dBc
	C/I_{Nth}	N th ACS C/I, $f_i > 6\text{MHz}$			-40		dBc
	C/I_{Nth}	N th ACS C/I, $f_i > 25\text{MHz}$	a		-47		dBc
250kbps	C/I_{CO}	C/I Co-channel			12		dBc
	C/I_{1ST}	1 st ACS C/I 1MHz			-12		dBc
	C/I_{2ND}	2 nd ACS C/I 2MHz			-33		dBc
	C/I_{3RD}	3 rd ACS C/I 3MHz			-38		dBc
	C/I_{Nth}	N th ACS C/I, $f_i > 6\text{MHz}$			-50		dBc
	C/I_{Nth}	N th ACS C/I, $f_i > 25\text{MHz}$	a		-60		dBc

a. Narrow Band (In Band) Blocking measurements:

0 to ±40MHz; 1MHz step size

For Interferer frequency offsets $n \cdot 2 \cdot f_{xtal}$, blocking performance is degraded by approximately 5dB compared to adjacent figures.

Table 8. RX selectivity according to ETSI EN 300 440-1 V1.3.1 (2001-09) page 27

Datarate	Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
2Mbps	C/I _{CO}	C/I Co-channel (Modulated carrier)			11		dBc
	C/I _{1ST}	1 st ACS C/I 2MHz			4		dBc
	C/I _{2ND}	2 nd ACS C/I 4MHz			-18		dBc
	C/I _{3RD}	3 rd ACS C/I 6MHz			-24		dBc
	C/I _{Nth}	N th ACS C/I, $f_i > 12\text{MHz}$			-40		dBc
	C/I _{Nth}	N th ACS C/I, $f_i > 36\text{MHz}$	a		-48		dBc
1Mbps	C/I _{CO}	C/I Co-channel			12		dBc
	C/I _{1ST}	1 st ACS C/I 1MHz			8		dBc
	C/I _{2ND}	2 nd ACS C/I 2MHz			-21		dBc
	C/I _{3RD}	3 rd ACS C/I 3MHz			-30		dBc
	C/I _{Nth}	N th ACS C/I, $f_i > 6\text{MHz}$			-40		dBc
	C/I _{Nth}	N th ACS C/I, $f_i > 25\text{MHz}$	a		-50		dBc
250kbps	C/I _{CO}	C/I Co-channel			7		dBc
	C/I _{1ST}	1 st ACS C/I 1MHz			-12		dBc
	C/I _{2ND}	2 nd ACS C/I 2MHz			-34		dBc
	C/I _{3RD}	3 rd ACS C/I 3MHz			-39		dBc
	C/I _{Nth}	N th ACS C/I, $f_i > 6\text{MHz}$			-50		dBc
	C/I _{Nth}	N th ACS C/I, $f_i > 25\text{MHz}$	a		-60		dBc

a. Narrow Band (In Band) Blocking measurements:

0 to ±40MHz; 1MHz step size

Wide Band Blocking measurements:

30MHz to 2000MHz; 10MHz step size

2000MHz to 2399MHz; 3MHz step size

2484MHz to 3000MHz; 3MHz step size

3GHz to 12.75GHz; 25MHz step size

Wanted signal for wideband blocking measurements:

-67dBm in 1Mbps and 2Mbps mode

-77dBm in 250kbps mode

For Interferer frequency offsets $n \cdot 2 \cdot f_{xtal}$, blocking performance are degraded by approximately 5dB compared to adjacent figures.

If the wanted signal is 3dB or more above the sensitivity level then, the carrier/interferer ratio is independent of the wanted signal level for a given frequency offset.

Table 9. RX selectivity with nRF24L01+ equal modulation on interfering signal. Measured using Pin = -67dBm for wanted signal.

Datarate	Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
2Mbps	P_IM(6)	Input power of IM interferers at 6 and 12MHz offset from wanted signal			-42		dBm
	P_IM(8)	Input power of IM interferers at 8 and 16MHz offset from wanted signal			-38		dBm
	P_IM(10)	Input power of IM interferers at 10 and 20MHz offset from wanted signal			-37		dBm
1Mbps	P_IM(3)	Input power of IM interferers at 3 and 6MHz offset from wanted signal			-36		dBm
	P_IM(4)	Input power of IM interferers at 4 and 8MHz offset from wanted signal			-36		dBm
	P_IM(5)	Input power of IM interferers at 5 and 10MHz offset from wanted signal			-36		dBm
250kbps	P_IM(3)	Input power of IM interferers at 3 and 6MHz offset from wanted signal			-36		dBm
	P_IM(4)	Input power of IM interferers at 4 and 8MHz offset from wanted signal			-36		dBm
	P_IM(5)	Input power of IM interferers at 5 and 10MHz offset from wanted signal			-36		dBm

Note: Wanted signal level at Pin = -64 dBm. Two interferers with equal input power are used. The interferer closest in frequency is unmodulated, the other interferer is modulated equal with the, wanted signal. The input power of interferers where the sensitivity equals BER = 0.1% is presented.

Table 10. RX intermodulation test performed according to Bluetooth Specification version 2.0

5.5 Crystal specifications

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
F _{xo}	Crystal Frequency			16		MHz
ΔF	Tolerance	a b			±60	ppm
C ₀	Equivalent parallel capacitance			1.5	7.0	pF
C _L	Load capacitance		8	12	16	pF
ESR	Equivalent Series Resistance				100	Ω

a. Frequency accuracy including; tolerance at 25°C, temperature drift, aging and crystal loading.

b. Frequency regulations in certain regions set tighter requirements for frequency tolerance (For example, Japan and South Korea specify max. +/- 50ppm)

Table 11. Crystal specifications

5.6 DC characteristics

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
V _{IH}	HIGH level input voltage		0.7V _{DD}		5.25 ^a	V
V _{IL}	LOW level input voltage		v _{SS}		0.3V _{DD}	V

a. If the input signal >3.6V, the V_{DD} of the nRF24L01+ must be between 2.7V and 3.3V (3.0V±10%)

Table 12. Digital input pin

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
V _{OH}	HIGH level output voltage (I _{OH} =-0.25mA)		V _{DD} -0.3		V _{DD}	V
V _{OL}	LOW level output voltage (I _{OL} =0.25mA)				0.3	V

Table 13. Digital output pin

5.7 Power on reset

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
T _{PUP}	Power ramp up time	a			100	ms
T _{POR}	Power on reset	b	1		100	ms

a. From 0V to 1.9V.

b. Measured from when the V_{DD} reaches 1.9V to when the reset finishes.

Table 14. Power on reset

6. Radio Control

This chapter describes the nRF24L01+ radio transceiver's operating modes and the parameters used to control the radio.

The nRF24L01+ has a built-in state machine that controls the transitions between the chip's operating modes. The state machine takes input from user defined register values and internal signals.

6.1 Operational Modes

You can configure the nRF24L01+ in power down, standby, RX or TX mode. This section describes these modes in detail.

6.1.1 State diagram

The state diagram in Figure 3. shows the operating modes and how they function. There are three types of distinct states highlighted in the state diagram:

- Recommended operating mode: is a recommended state used during normal operation.
- Possible operating mode: is a possible operating state, but is not used during normal operation.
- Transition state: is a time limited state used during start up of the oscillator and settling of the PLL.

When the V_{DD} reaches 1.9V or higher nRF24L01+ enters the Power on reset state where it remains in reset until entering the Power Down mode.

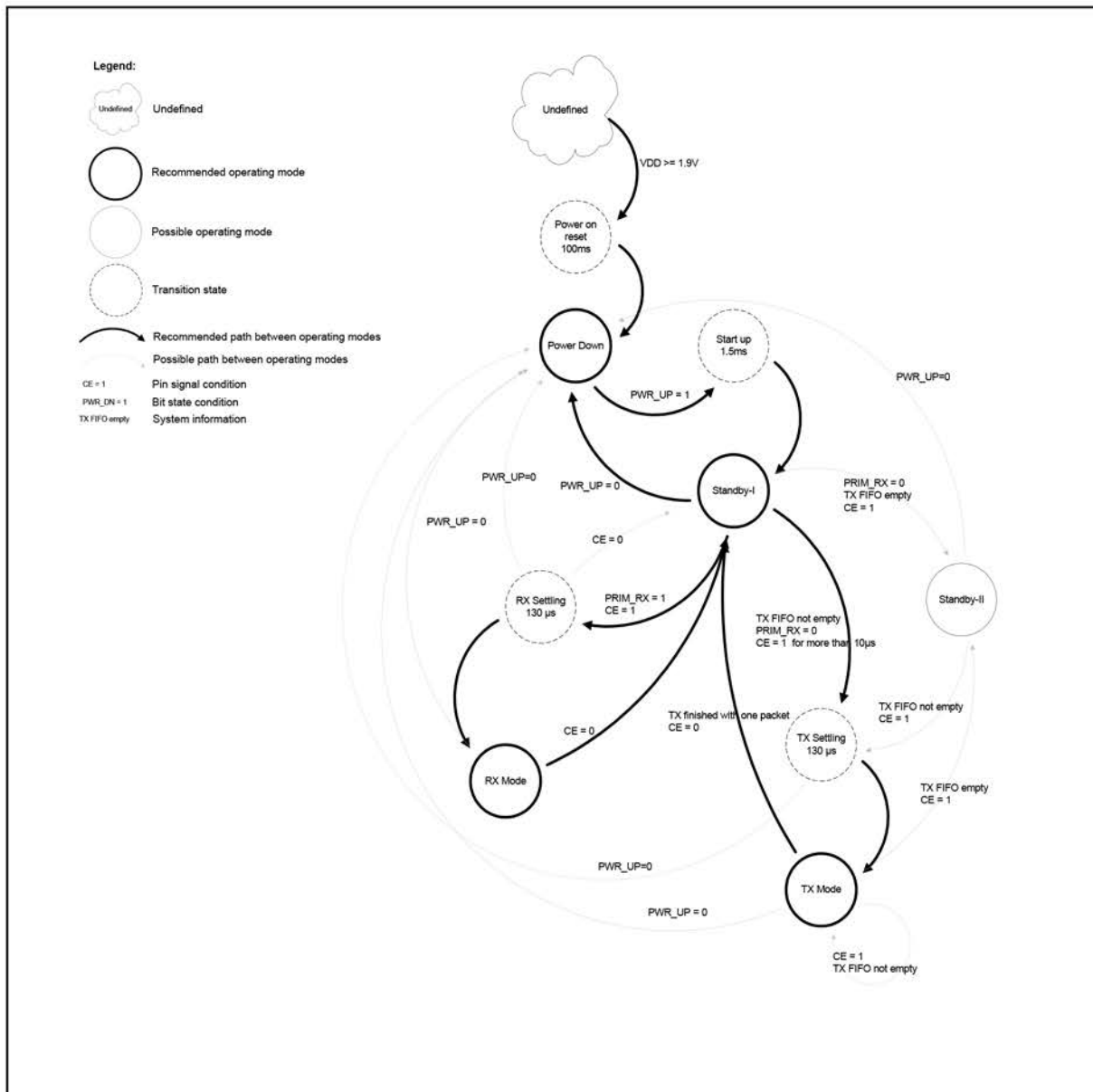


Figure 3. Radio control state diagram

6.1.2 Power Down Mode

In power down mode nRF24L01+ is disabled using minimal current consumption. All register values available are maintained and the SPI is kept active, enabling change of configuration and the uploading/downloading of data registers. For start up times see Table 16.

Power down mode is entered by setting the PWR_UP bit in the CONFIG register low.

6.1.3 Standby Modes

6.1.3.1 Standby-I mode

By setting the PWR_UP bit in the CONFIG register to 1, the device enters standby-I mode. Standby-I mode is used to minimize average current consumption while maintaining short start up times. In this mode only part of the crystal oscillator is active. Change to active modes only happens if CE is set high and when CE is set low, the nRF24L01 returns to standby-I mode from both the TX and RX modes.

6.1.3.2 Standby-II mode

In standby-II mode extra clock buffers are active and more current is used compared to standby-I mode. nRF24L01+ enters standby-II mode if CE is held high on a PTX device with an empty TX FIFO. If a new packet is uploaded to the TX FIFO, the PLL immediately starts and the packet is transmitted after the normal PLL settling delay (130µs).

Register values are maintained and the SPI can be activated during both standby modes. For start up times see Table 16.

6.1.4 RX mode

The RX mode is an active mode where the nRF24L01+ radio is used as a receiver. To enter this mode, the nRF24L01+ must have the PWR_UP bit, PRIM_RX bit and the CE pin set high. In RX mode the receiver demodulates the signals from the RF channel, constantly presenting the demodulated data to the baseband protocol engine. The baseband protocol engine constantly searches for a valid packet. If a valid packet is found (by a matching address and a valid CRC) the payload of the packet is presented in a vacant slot in the RX FIFOs. If the RX FIFOs are full, the received packet is discarded. The nRF24L01+ remains in RX mode until the MCU configures it to standby-I mode or power down mode. However, if the automatic protocol features (Enhanced ShockBurst™) in the baseband protocol engine are enabled, the nRF24L01+ can enter other modes in order to execute the protocol.

In RX mode a Received Power Detector (RPD) signal is available. The RPD is a signal that is set high when a RF signal higher than -64 dBm is detected inside the receiving frequency channel. The internal RPD signal is filtered before presented to the RPD register. The RF signal must be present for at least 40µs before the RPD is set high. How to use the RPD is described in Section 6.4.

6.1.5 TX mode

The TX mode is an active mode for transmitting packets. To enter this mode, the nRF24L01+ must have the PWR_UP bit set high, PRIM_RX bit set low, a payload in the TX FIFO and a high pulse on the CE for more than 10µs.

6.1.7 Timing Information

The timing information in this section relates to the transitions between modes and the timing for the CE pin. The transition from TX mode to RX mode or vice versa is the same as the transition from the standby modes to TX mode or RX mode (max. 130µs), as described in Table 16.

Name	nRF24L01+	Max.	Min.	Comments
Tpd2stby	Power Down → Standby mode	1.5ms		Internal crystal oscillator
Tpd2stby	Power Down → Standby mode	150µs		With external clock
Tstby2a	Standby modes → TX/RX mode	130µs		
Thce	Minimum CE high		10µs	
Tpece2csn	Delay from CE positive edge to CSN low		4µs	

Table 16. Operational timing of nRF24L01+

When nRF24L01+ is in power down mode it must settle for 1.5ms before it can enter the TX or RX modes. If an external clock is used this delay is reduced to 150µs, see Table 16.. The settling time must be controlled by the MCU.

Note: If V_{DD} is turned off the register value is lost and you must configure nRF24L01+ before entering the TX or RX modes.

6.2 Air data rate

The air data rate is the modulated signaling rate the nRF24L01+ uses when transmitting and receiving data. It can be 250kbps, 1Mbps or 2Mbps. Using lower air data rate gives better receiver sensitivity than higher air data rate. But, high air data rate gives lower average current consumption and reduced probability of on-air collisions.

The air data rate is set by the RF_DR bit in the RF_SETUP register. A transmitter and a receiver must be programmed with the same air data rate to communicate with each other. nRF24L01+ is fully compatible with nRF24L01. For compatibility with nRF2401A, nRF2402, nRF24E1, and nRF24E2 the air data rate must be set to 250kbps or 1Mbps.

6.3 RF channel frequency

The RF channel frequency determines the center of the channel used by the nRF24L01+. The channel occupies a bandwidth of less than 1MHz at 250kbps and 1Mbps and a bandwidth of less than 2MHz at 2Mbps. nRF24L01+ can operate on frequencies from 2.400GHz to 2.525GHz. The programming resolution of the RF channel frequency setting is 1MHz.

At 2Mbps the channel occupies a bandwidth wider than the resolution of the RF channel frequency setting. To ensure non-overlapping channels in 2Mbps mode, the channel spacing must be 2MHz or more. At 1Mbps and 250kbps the channel bandwidth is the same or lower than the resolution of the RF frequency.

The RF channel frequency is set by the RF_CH register according to the following formula:

$$F_0 = 2400 + \text{RF_CH [MHz]}$$

You must program a transmitter and a receiver with the same RF channel frequency to communicate with each other.

6.4 Received Power Detector measurements

Received Power Detector (RPD), located in register 09, bit 0, triggers at received power levels above -64 dBm that are present in the RF channel you receive on. If the received power is less than -64 dBm, RDP = 0.

The RPD can be read out at any time while nRF24L01+ is in receive mode. This offers a snapshot of the current received power level in the channel. The RPD status is latched when a valid packet is received which then indicates signal strength from your own transmitter. If no packets are received the RPD is latched at the end of a receive period as a result of host MCU setting CE low or RX time out controlled by Enhanced ShockBurst™.

The status of RPD is correct when RX mode is enabled and after a wait time of $T_{\text{stby2a}} + T_{\text{delay_AGC}} = 130\mu\text{s} + 40\mu\text{s}$. The RX gain varies over temperature which means that the RPD threshold also varies over temperature. The RPD threshold value is reduced by -5dB at $T = -40^\circ\text{C}$ and increased by +5dB at 85°C .

6.5 PA control

The PA (Power Amplifier) control is used to set the output power from the nRF24L01+ power amplifier. In TX mode PA control has four programmable steps, see Table 17.

The PA control is set by the RF_PWR bits in the RF_SETUP register.

SPI RF-SETUP (RF_PWR)	RF output power	DC current consumption
11	0dBm	11.3mA
10	-6dBm	9.0mA
01	-12dBm	7.5mA
00	-18dBm	7.0mA

Conditions: $V_{\text{DD}} = 3.0\text{V}$, $V_{\text{SS}} = 0\text{V}$, $T_{\text{A}} = 27^\circ\text{C}$, Load impedance = $15\Omega + j88\Omega$.

Table 17. RF output power setting for the nRF24L01+

6.6 RX/TX control

The RX/TX control is set by PRIM_RX bit in the CONFIG register and sets the nRF24L01+ in transmit/receive mode.

7. Enhanced ShockBurst™

Enhanced ShockBurst™ is a packet based data link layer that features automatic packet assembly and timing, automatic acknowledgement and retransmissions of packets. Enhanced ShockBurst™ enables the implementation of ultra low power and high performance communication with low cost host microcontrollers. The Enhanced ShockBurst™ features enable significant improvements of power efficiency for bidirectional and uni-directional systems, without adding complexity on the host controller side.

7.1 Features

The main features of Enhanced ShockBurst™ are:

- 1 to 32 bytes dynamic payload length
- Automatic packet handling
- Automatic packet transaction handling
 - > Auto Acknowledgement with payload
 - > Auto retransmit
- 6 data pipe MultiCeiver™ for 1:6 star networks

7.2 Enhanced ShockBurst™ overview

Enhanced ShockBurst™ uses ShockBurst™ for automatic packet handling and timing. During transmit, ShockBurst™ assembles the packet and clocks the bits in the data packet for transmission. During receive, ShockBurst™ constantly searches for a valid address in the demodulated signal. When ShockBurst™ finds a valid address, it processes the rest of the packet and validates it by CRC. If the packet is valid the payload is moved into a vacant slot in the RX FIFOs. All high speed bit handling and timing is controlled by ShockBurst™. Enhanced ShockBurst™ features automatic packet transaction handling for the easy implementation of a reliable bi-directional data link. An Enhanced ShockBurst™ packet transaction is a packet exchange between two transceivers, with one transceiver acting as the Primary Receiver (PRX) and the other transceiver acting as the Primary Transmitter (PTX). An Enhanced ShockBurst™ packet transaction is always initiated by a packet transmission from the PTX, the transaction is complete when the PTX has received an acknowledgment packet (ACK packet) from the PRX. The PRX can attach user data to the ACK packet enabling a bi-directional data link.

The automatic packet transaction handling works as follows:

1. You begin the transaction by transmitting a data packet from the PTX to the PRX. Enhanced ShockBurst™ automatically sets the PTX in receive mode to wait for the ACK packet.
2. If the packet is received by the PRX, Enhanced ShockBurst™ automatically assembles and transmits an acknowledgment packet (ACK packet) to the PTX before returning to receive mode.
3. If the PTX does not receive the ACK packet immediately, Enhanced ShockBurst™ automatically retransmits the original data packet after a programmable delay and sets the PTX in receive mode to wait for the ACK packet.

In Enhanced ShockBurst™ it is possible to configure parameters such as the maximum number of retransmits and the delay from one transmission to the next retransmission.

All automatic handling is done without the involvement of the MCU.

7.3 Enhanced Shockburst™ packet format

The format of the Enhanced ShockBurst™ packet is described in this section. The Enhanced Shock-Burst™ packet contains a preamble, address, packet control, payload and CRC field.

Figure 4. shows the packet format with MSB to the left.



Figure 4. An Enhanced ShockBurst™ packet with payload (0-32 bytes)

7.3.1 Preamble

The preamble is a bit sequence used to synchronize the receivers demodulator to the incoming bit stream. The preamble is one byte long and is either 01010101 or 10101010. If the first bit in the address is 1 the preamble is automatically set to 10101010 and if the first bit is 0 the preamble is automatically set to 01010101. This is done to ensure there are enough transitions in the preamble to stabilize the receiver.

7.3.2 Address

This is the address for the receiver. An address ensures that the packet is detected and received by the correct receiver, preventing accidental cross talk between multiple nRF24L01+ systems. You can configure the address field width in the AW register to be 3, 4 or 5 bytes, see Table 27.

Note: Addresses where the level shifts only one time (that is, 000FFFFFFF) can often be detected in noise and can give a false detection, which may give a raised Packet Error Rate. Addresses as a continuation of the preamble (hi-low toggling) also raises the Packet Error Rate.

7.3.3 Packet Control Field

Figure 5. shows the format of the 9 bit packet control field, MSB to the left.



Figure 5. Packet control field

The packet control field contains a 6 bit payload length field, a 2 bit PID (Packet Identity) field and a 1 bit NO_ACK flag.

7.3.3.1 Payload length

This 6 bit field specifies the length of the payload in bytes. The length of the payload can be from 0 to 32 bytes.

Coding: 000000 = 0 byte (only used in empty ACK packets.) 100000 = 32 byte,
100001 = Don't care.

This field is only used if the Dynamic Payload Length function is enabled.

7.3.3.2 PID (Packet identification)

The 2 bit PID field is used to detect if the received packet is new or retransmitted. PID prevents the PRX device from presenting the same payload more than once to the receiving host MCU. The PID field is incremented at the TX side for each new packet received through the SPI. The PID and CRC fields (see section 7.3.5) are used by the PRX device to determine if a packet is retransmitted or new. When several data packets are lost on the link, the PID fields may become equal to the last received PID. If a packet has the same PID as the previous packet, nRF24L01+ compares the CRC sums from both packets. If the CRC sums are also equal, the last received packet is considered a copy of the previously received packet and discarded.

7.3.3.3 No Acknowledgment flag (NO_ACK)

The Selective Auto Acknowledgement feature controls the NO_ACK flag.

This flag is only used when the auto acknowledgement feature is used. Setting the flag high tells the receiver that the packet is not to be auto acknowledged.

7.3.4 Payload

The payload is the user defined content of the packet. It can be 0 to 32 bytes wide and is transmitted on-air when it is uploaded to nRF24L01+.

7.3.5 CRC (Cyclic Redundancy Check)

The CRC is the mandatory error detection mechanism in the packet. It is either 1 or 2 bytes and is calculated over the address, Packet Control Field and Payload.

The polynomial for 1 byte CRC is $X^8 + X^2 + X + 1$. Initial value 0xFF.

The polynomial for 2 byte CRC is $X^{16} + X^{12} + X^5 + 1$. Initial value 0xFFFF.

No packet is accepted by Enhanced ShockBurst™ if the CRC fails.

7.4 Automatic packet handling

Enhanced ShockBurst™ uses ShockBurst™ for automatic packet handling, which has the following features:

- Static and dynamic payload length, see section 7.4.1
- Automatic packet assembly, see section 7.4.2
- Automatic packet validation, see section 7.4.3
- Automatic packet disassembly, see section 7.4.4

7.4.1 Static and Dynamic Payload Length

Enhanced ShockBurst™ provides two alternatives for handling payload lengths; static and dynamic. The default is static payload length. With static payload length all packets between a transmitter and a receiver have the same length. Static payload length is set by the RX_PW_Px registers on the receiver side. The payload length on the transmitter side is set by the number of bytes clocked into the TX_FIFO and must equal the value in the RX_PW_Px register on the receiver side. Dynamic Payload Length (DPL) is an alternative to static payload length. DPL enables the transmitter to send packets with variable payload length to the receiver.

This means that for a system with different payload lengths it is not necessary to scale the packet length to the longest payload. With the DPL feature the nRF24L01+ can decode the payload length of the received packet automatically instead of using the RX_PW_Px registers. The MCU can read the length of the received payload by using the R_RX_PL_WID command. In order to enable DPL the EN_DPL bit in the FEATURE register must be enabled. In RX mode the DYNPD register must be set. A PTX that transmits to a PRX with DPL enabled must have the DPL_PO bit in DYNPD set.

7.4.2 Automatic packet assembly

The automatic packet assembly assembles the preamble, address, packet control field, payload and CRC to make a complete packet before it is transmitted.

7.4.2.1 Preamble

The preamble is automatically generated based on the address field.

7.4.2.2 Address

The address is fetched from the TX_ADDR register. The address field can be configured to be 3, 4 or 5 bytes long with the AW register.

7.4.2.3 Packet control field

For the static packet length option the payload length field is not used. With DPL enabled, the value in the payload length field is automatically set to the number of bytes in the payload clocked into the TX FIFO. The transmitter increments the PID field each time it generates a new packet and uses the same PID on packets that are retransmitted. Refer to the left flow chart in Figure 6.

The PTX can set the NO_ACK flag bit in the Packet Control Field with this command:

```
W_TX_PAYLOAD_NOACK
```

However, the function must first be enabled in the FEATURE register by setting the EN_DYN_ACK bit.

When you use this option the PTX goes directly to standby-I mode after transmitting the packet. The PRX does not transmit an ACK packet when it receives the packet.

7.4.2.4 Payload

The payload is fetched from the TX FIFO.

7.4.2.5 CRC

The CRC is automatically calculated based on the packet content with the polynomials in section 7.3.5. The number of bytes in the CRC is set by the CRCO bit in the CONFIG register.

7.4.3 Automatic packet validation

In receive mode the nRF24L01+ is constantly searching for a valid address

(given in the RX_ADDR registers). If a valid address is detected, Enhanced ShockBurst™ starts to validate the packet. With static packet length the Enhanced ShockBurst™ captures the packet according to the length given by the RX_PW register. With DPL, Enhanced ShockBurst™ captures the packet according to the payload length field in the packet control field.

After capturing the packet, Enhanced ShockBurst™ performs CRC. If the CRC is valid, Enhanced ShockBurst™ checks PID. The received PID is compared with the previous received PID.

If the PID fields are different, the packet is considered new. If the PID fields are equal the receiver must check if the received CRC is equal to the previous CRC. If the CRCs are equal, the packet is defined as equal to the previous packet and is discarded. Refer to the right flow chart in Figure 6.

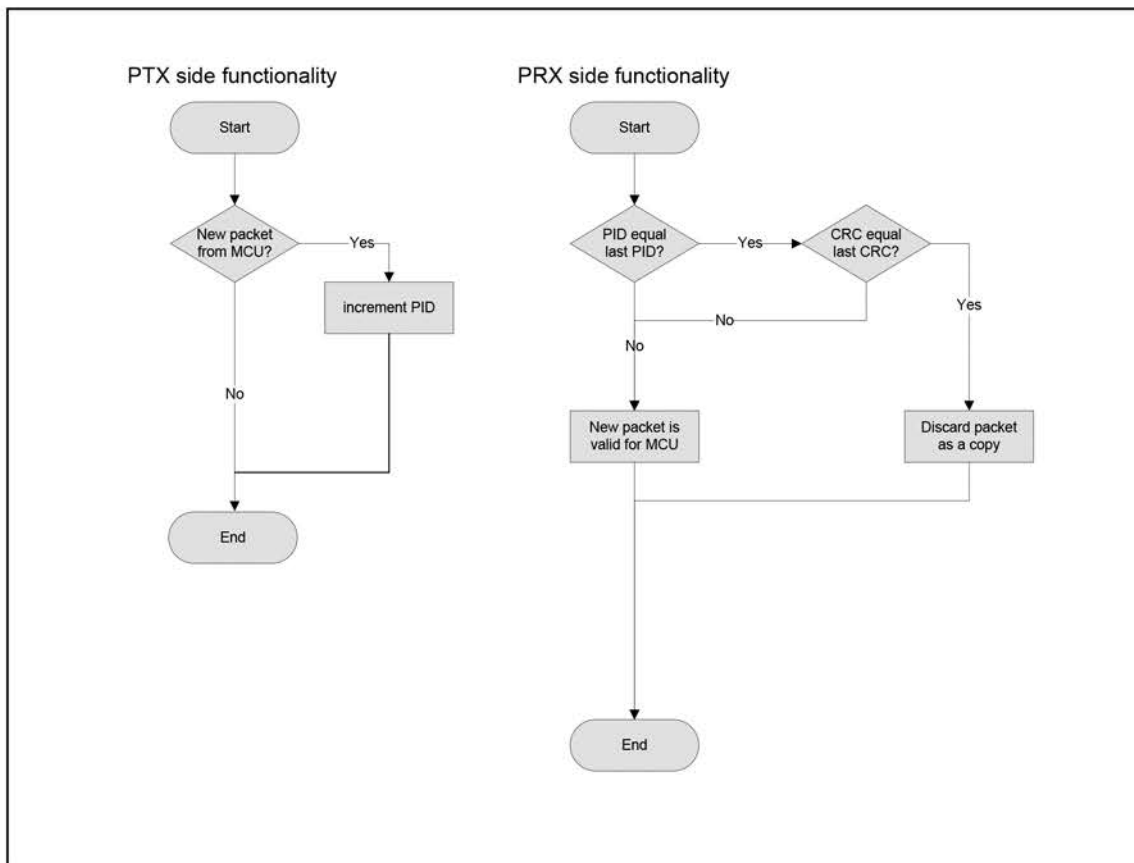


Figure 6. PID generation/detection

7.4.4 Automatic packet disassembly

After the packet is validated, Enhanced ShockBurst™ disassembles the packet and loads the payload into the RX FIFO, and asserts the RX_DR IRQ.

7.5 Automatic packet transaction handling

Enhanced ShockBurst™ has two functions for automatic packet transaction handling; auto acknowledgement and auto re-transmit.

7.5.1 Auto Acknowledgement

Auto acknowledgment is a function that automatically transmits an ACK packet to the PTX after it has received and validated a packet. The auto acknowledgment function reduces the load of the system MCU and can remove the need for dedicated SPI hardware.

This also reduces cost and average current consumption. The Auto Acknowledgement feature is enabled by setting the EN_AA register.

Note: If the received packet has the NO_ACK flag set, auto acknowledgement is not executed.

An ACK packet can contain an optional payload from PRX to PTX. In order to use this feature, the Dynamic Payload Length (DPL) feature must be enabled. The MCU on the PRX side has to upload the payload by clocking it into the TX FIFO by using the `W_ACK_PAYLOAD` command. The payload is pending in the TX FIFO (PRX) until a new packet is received from the PTX. nRF24L01+ can have three ACK packet payloads pending in the TX FIFO (PRX) at the same time.

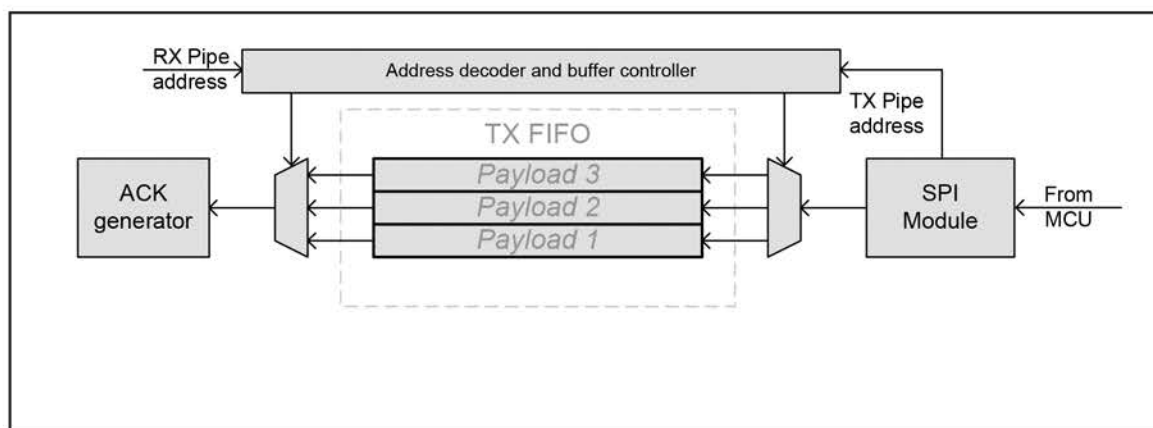


Figure 7. TX FIFO (PRX) with pending payloads

Figure 7. shows how the TX FIFO (PRX) is operated when handling pending ACK packet payloads. From the MCU the payload is clocked in with the `W_ACK_PAYLOAD` command. The address decoder and buffer controller ensure that the payload is stored in a vacant slot in the TX FIFO (PRX). When a packet is received, the address decoder and buffer controller are notified with the PTX address. This ensures that the right payload is presented to the ACK generator.

If the TX FIFO (PRX) contains more than one payload to a PTX, payloads are handled using the first in – first out principle. The TX FIFO (PRX) is blocked if all pending payloads are addressed to a PTX where the link is lost. In this case, the MCU can flush the TX FIFO (PRX) by using the `FLUSH_TX` command. In order to enable Auto Acknowledgement with payload the `EN_ACK_PAY` bit in the `FEATURE` register must be set.

7.5.2 Auto Retransmission (ART)

The auto retransmission is a function that retransmits a packet if an ACK packet is not received. It is used in an auto acknowledgement system on the PTX. When a packet is not acknowledged, you can set the number of times it is allowed to retransmit by setting the `ARC` bits in the `SETUP_RETR` register. PTX enters RX mode and waits a time period for an ACK packet each time a packet is transmitted. The amount of time the PTX is in RX mode is based on the following conditions:

- Auto Retransmit Delay (ARD) elapsed.
- No address match within 250µs.
- After received packet (CRC correct or not) if address match within 250µs.

nRF24L01+ asserts the TX_DS IRQ when the ACK packet is received.

nRF24L01+ enters standby-I mode if there is no more untransmitted data in the TX FIFO and the CE pin is low. If the ACK packet is not received, nRF24L01+ goes back to TX mode after a delay defined by ARD and retransmits the data. This continues until acknowledgment is received, or the maximum number of retransmits is reached.

Two packet loss counters are incremented each time a packet is lost, ARC_CNT and PLOS_CNT in the OBSERVE_TX register. The ARC_CNT counts the number of retransmissions for the current transaction.

You reset ARC_CNT by initiating a new transaction. The PLOS_CNT counts the total number of retransmissions since the last channel change. You reset PLOS_CNT by writing to the RF_CH register. It is possible to use the information in the OBSERVE_TX register to make an overall assessment of the channel quality.

The ARD defines the time from the end of a transmitted packet to when a retransmit starts on the PTX. ARD is set in SETUP_RETR register in steps of 250µs. A retransmit is made if no ACK packet is received by the PTX.

There is a restriction on the length of ARD when using ACK packets with payload. The ARD time must never be shorter than the sum of the startup time and the time on-air for the ACK packet. For 1Mbps data rate and 5 byte address; 5 byte is maximum ACK packet payload length for ARD=250µs (reset value).

For 2Mbps data rate and 5 byte address; 15 byte is maximum ACK packet payload length for ARD=250µs (reset value).

ARD=500µs is long enough for any ACK payload length.

As an alternative to Auto Retransmit it is possible to manually set the nRF24L01+ to retransmit a packet a number of times. This is done by the REUSE_TX_PL command.

The MCU must initiate each transmission of the packet with a pulse on the CE pin when this command is used.

7.6 Enhanced ShockBurst flowcharts

This section contains flowcharts outlining PTX and PRX operation in Enhanced ShockBurst™.

7.6.1 PTX operation

The flowchart in Figure 8. outlines how a nRF24L01+ configured as a PTX behaves after entering standby-I mode.

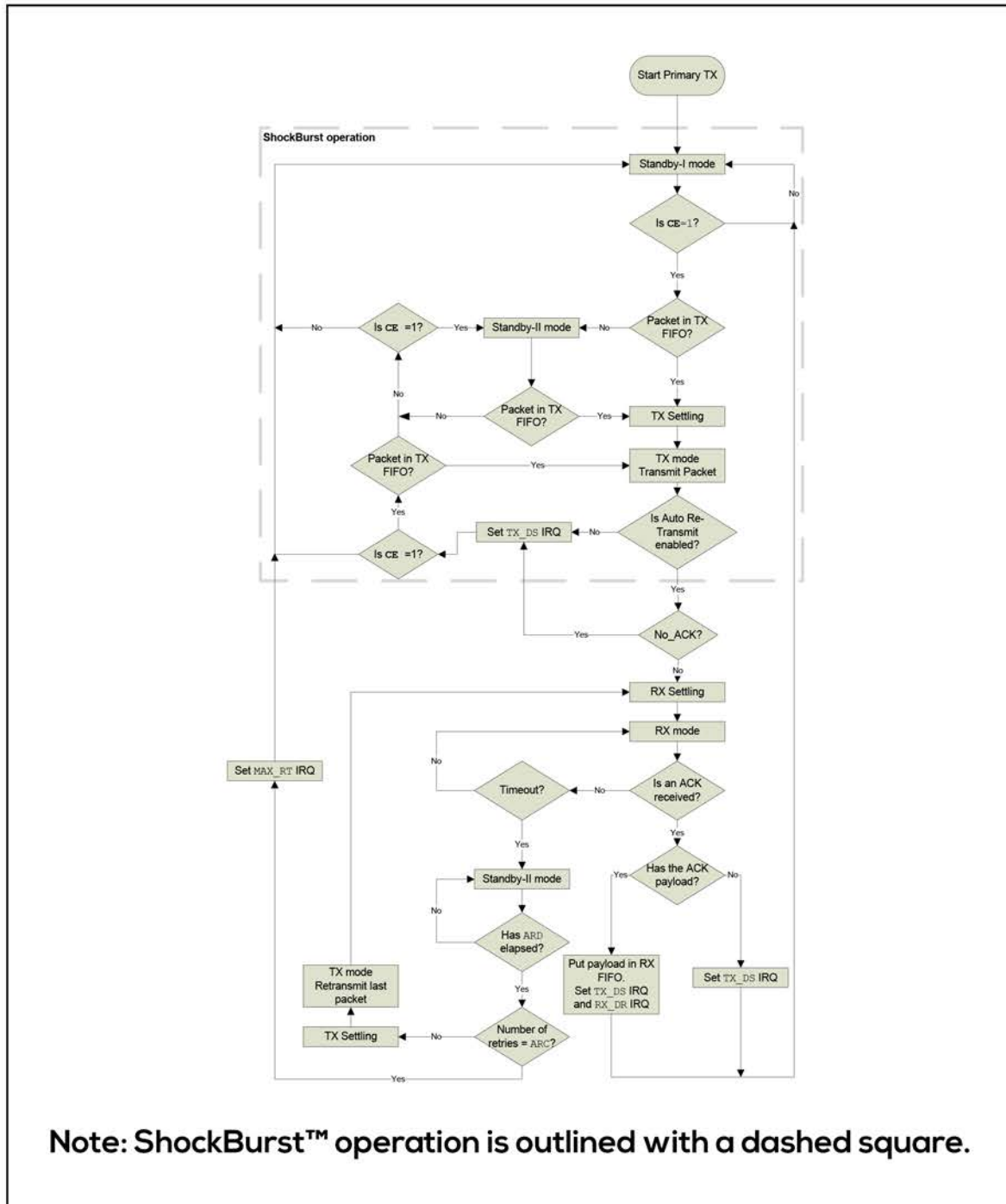


Figure 8. PTX operations in Enhanced ShockBurst™

7.6.2 PRX operation

The flowchart in Figure 9. outlines how a nRF24L01+ configured as a PRX behaves after entering standby-l mode.

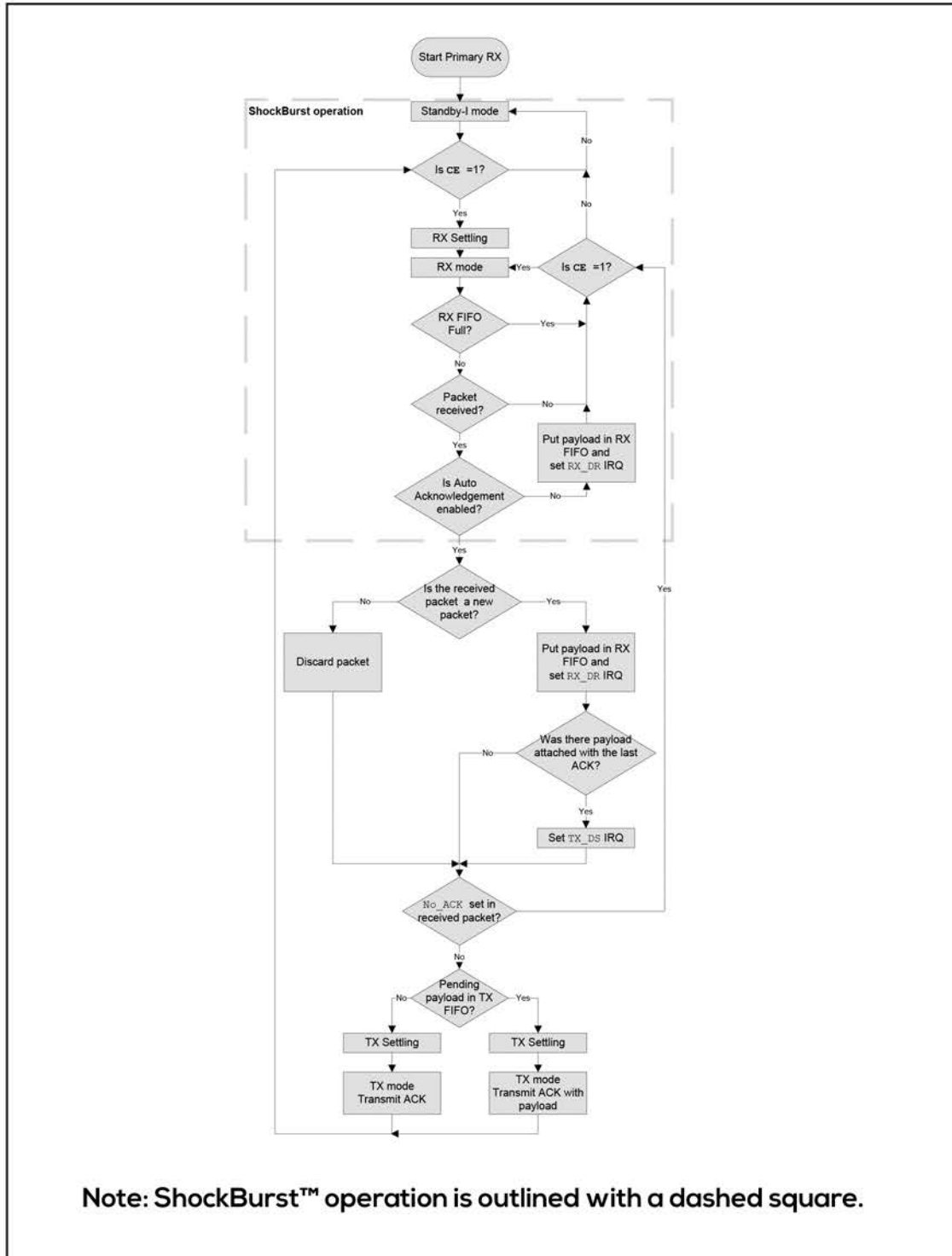


Figure 9. PRX operations in Enhanced ShockBurst™

Activate PRX mode by setting the CE pin high. The nRF24L01+ enters RX mode and starts searching for packets. If a packet is received and Auto Acknowledgement is enabled, nRF24L01+ decides if the packet is new or a copy of a previously received packet. If the packet is new the payload is made available in the RX FIFO and the RX_DR IRQ is asserted. If the last received packet from the transmitter is acknowledged with an ACK packet with payload, the TX_DS IRQ indicates that the PTX received the ACK packet with payload. If the No_ACK flag is not set in the received packet, the PRX enters TX mode. If there is a pending payload in the TX FIFO it is attached to the ACK packet. After the ACK packet is transmitted, the nRF24L01+ returns to RX mode. A copy of a previously received packet might be received if the ACK packet is lost. In this case, the PRX discards the received packet and transmits an ACK packet before it returns to RX mode.

7.7 MultiCeiver™

MultiCeiver™ is a feature used in RX mode that contains a set of six parallel data pipes with unique addresses. A data pipe is a logical channel in the physical RF channel. Each data pipe has its own physical address (data pipe address) decoding in the nRF24L01+.

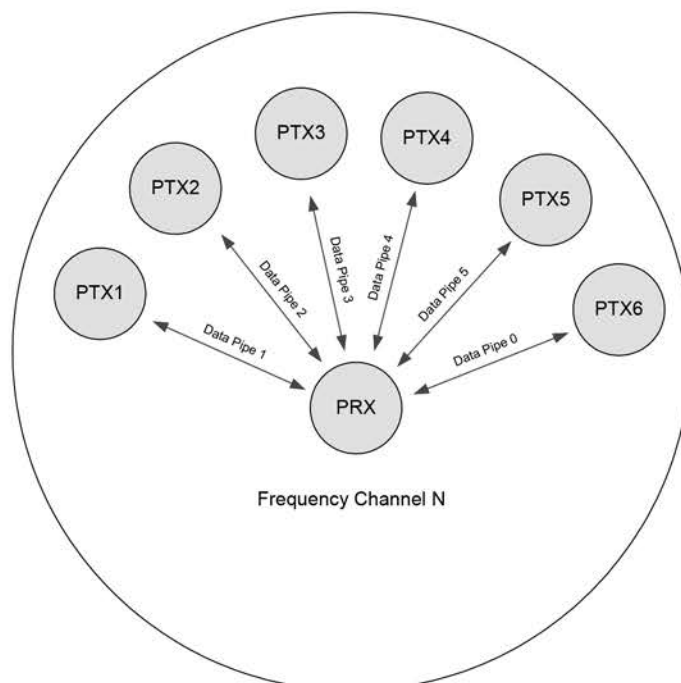


Figure 10. PRX using MultiCeiver™

nRF24L01+ configured as PRX (primary receiver) can receive data addressed to six different data pipes in one frequency channel as shown in Figure 10. Each data pipe has its own unique address and can be configured for individual behavior.

Up to six nRF24L01+s configured as PTX can communicate with one nRF24L01+ configured as a PRX. All data pipe addresses are searched for simultaneously. Only one data pipe can receive a packet at a time.

All data pipes can perform Enhanced ShockBurst™ functionality.

The following settings are common to all data pipes:

- CRC enabled/disabled (CRC always enabled when Enhanced ShockBurst™ is enabled)
- CRC encoding scheme
- RX address width
- Frequency channel
- Air data rate
- LNA gain

The data pipes are enabled with the bits in the EN_RXADDR register. By default only data pipe 0 and 1 are enabled. Each data pipe address is configured in the RX_ADDR_PX registers.

Note: Always ensure that none of the data pipes have the same address.

Each pipe can have up to a 5 byte configurable address. Data pipe 0 has a unique 5 byte address. Data pipes 1-5 share the four most significant address bytes. The LSByte must be unique for all six pipes. Figure 11. is an example of how data pipes 0-5 are addressed.

	Byte 4	Byte 3	Byte 2	Byte 1	Byte 0
Data pipe 0 (RX_ADDR_P0)	0xE7	0xD3	0xF0	0x35	0x77
Data pipe 1 (RX_ADDR_P1)	0xC2	0xC2	0xC2	0xC2	0xC2
	↓	↓	↓	↓	
Data pipe 2 (RX_ADDR_P2)	0xC2	0xC2	0xC2	0xC2	0xC3
	↓	↓	↓	↓	
Data pipe 3 (RX_ADDR_P3)	0xC2	0xC2	0xC2	0xC2	0xC4
	↓	↓	↓	↓	
Data pipe 4 (RX_ADDR_P4)	0xC2	0xC2	0xC2	0xC2	0xC5
	↓	↓	↓	↓	
Data pipe 5 (RX_ADDR_P5)	0xC2	0xC2	0xC2	0xC2	0xC6

Figure 11. Addressing data pipes 0-5

The PRX, using MultiCeiver™ and Enhanced ShockBurst™, receives packets from more than one PTX. To ensure that the ACK packet from the PRX is transmitted to the correct PTX, the PRX takes the data pipe address where it received the packet and uses it as the TX address when transmitting the ACK packet. Figure 12. is an example of an address configuration for the PRX and PTX. On the PRX the RX_ADDR_Pn, defined as the pipe address, must be unique. On the PTX the TX_ADDR must be the same as the RX_ADDR_P0 and as the pipe address for the designated pipe.

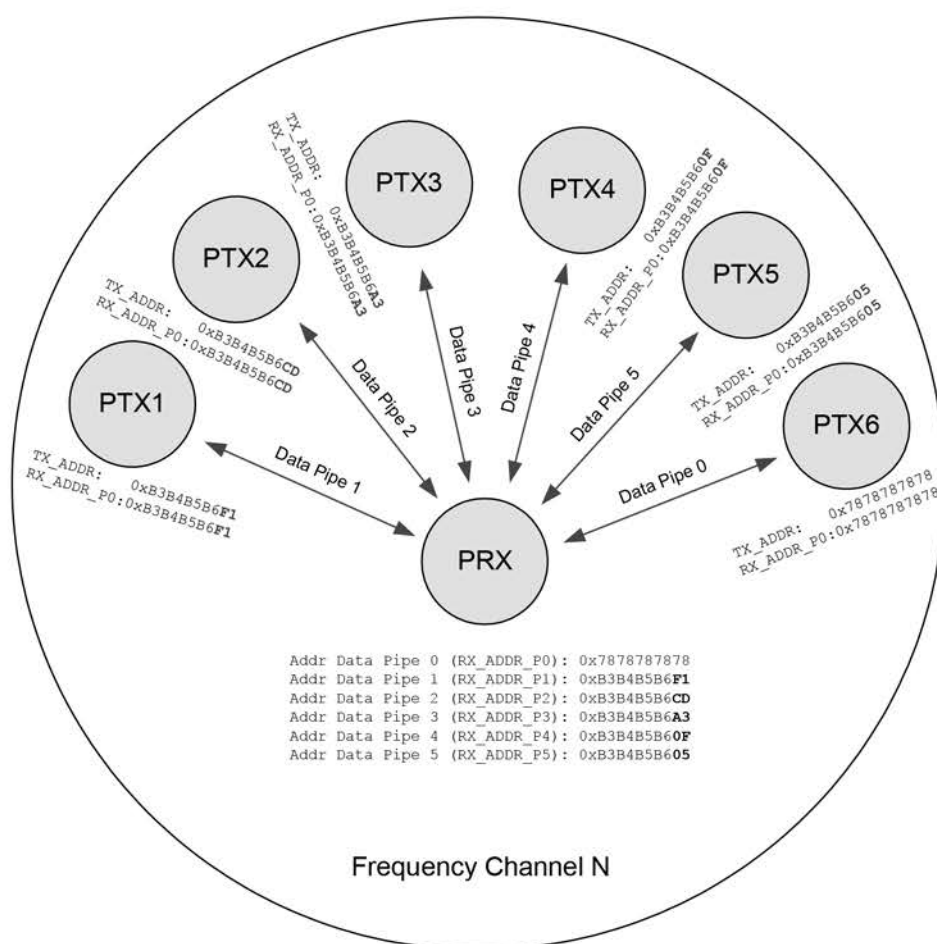


Figure 12. Example of data pipe addressing in MultiCeiver™

Only when a data pipe receives a complete packet can other data pipes begin to receive data. When multiple PTXs are transmitting to a PRX, the ARD can be used to skew the auto retransmission so that they only block each other once.

7.8 Enhanced ShockBurst™ timing

This section describes the timing sequence of Enhanced ShockBurst™ and how all modes are initiated and operated. The Enhanced ShockBurst™ timing is controlled through the Data and Control interface. The nRF24L01+ can be set to static modes or autonomous modes where the internal state machine controls the events. Each autonomous mode/sequence ends with an interrupt at the IRQ pin. All the interrupts are indicated as IRQ events in the timing diagrams.

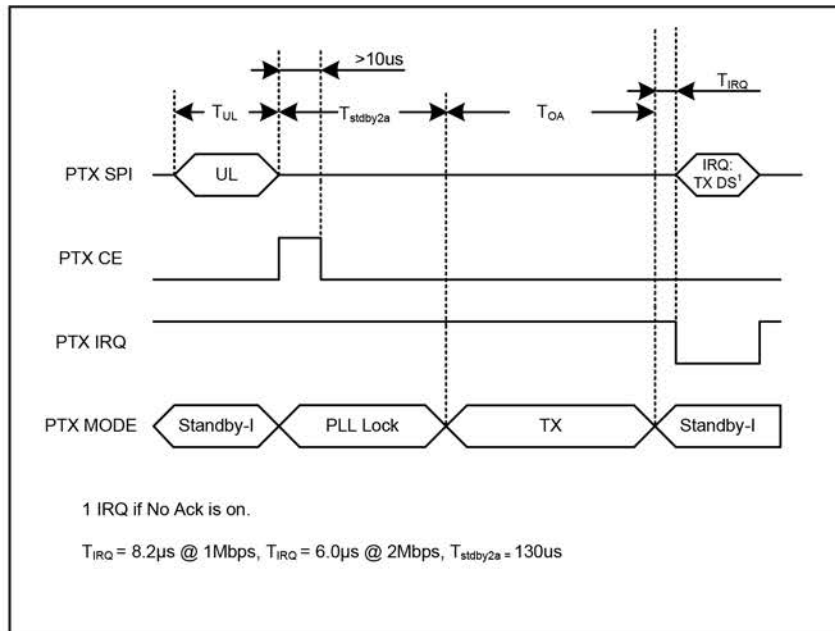


Figure 13. Transmitting one packet with NO_ACK on

The following equations calculate various timing measurements:

Symbol	Description	Equation
T_{OA}	Time on-air	$T_{OA} = \frac{\text{packet length}}{\text{air data rate}} = \frac{8 \left[\frac{\text{bit}}{\text{byte}} \right] \cdot \left(1 \left[\text{byte} \right] + 3,4 \text{ or } 5 \left[\text{bytes} \right] + N \left[\text{bytes} \right] + 1 \text{ or } 2 \left[\text{bytes} \right] \right) + 9 \left[\text{bit} \right]}{\text{air data rate} \left[\frac{\text{bit}}{\text{s}} \right]}$
T_{ACK}	Time on-air Ack	$T_{ACK} = \frac{\text{packet length}}{\text{air data rate}} = \frac{8 \left[\frac{\text{bit}}{\text{byte}} \right] \cdot \left(1 \left[\text{byte} \right] + 3,4 \text{ or } 5 \left[\text{bytes} \right] + N \left[\text{bytes} \right] + 1 \text{ or } 2 \left[\text{bytes} \right] \right) + 9 \left[\text{bit} \right]}{\text{air data rate} \left[\frac{\text{bit}}{\text{s}} \right]}$
T_{UL}	Time Upload	$T_{UL} = \frac{\text{payload length}}{\text{SPI data rate}} = \frac{8 \left[\frac{\text{bit}}{\text{byte}} \right] \cdot N \left[\text{bytes} \right]}{\text{SPI data rate} \left[\frac{\text{bit}}{\text{s}} \right]}$
T_{ESB}	Time Enhanced Shock-Burst™ cycle	$T_{ESB} = T_{UL} + 2 \cdot T_{stdby2a} + T_{OA} + T_{ACK} + T_{IRQ}$

Table 18. Timing equations

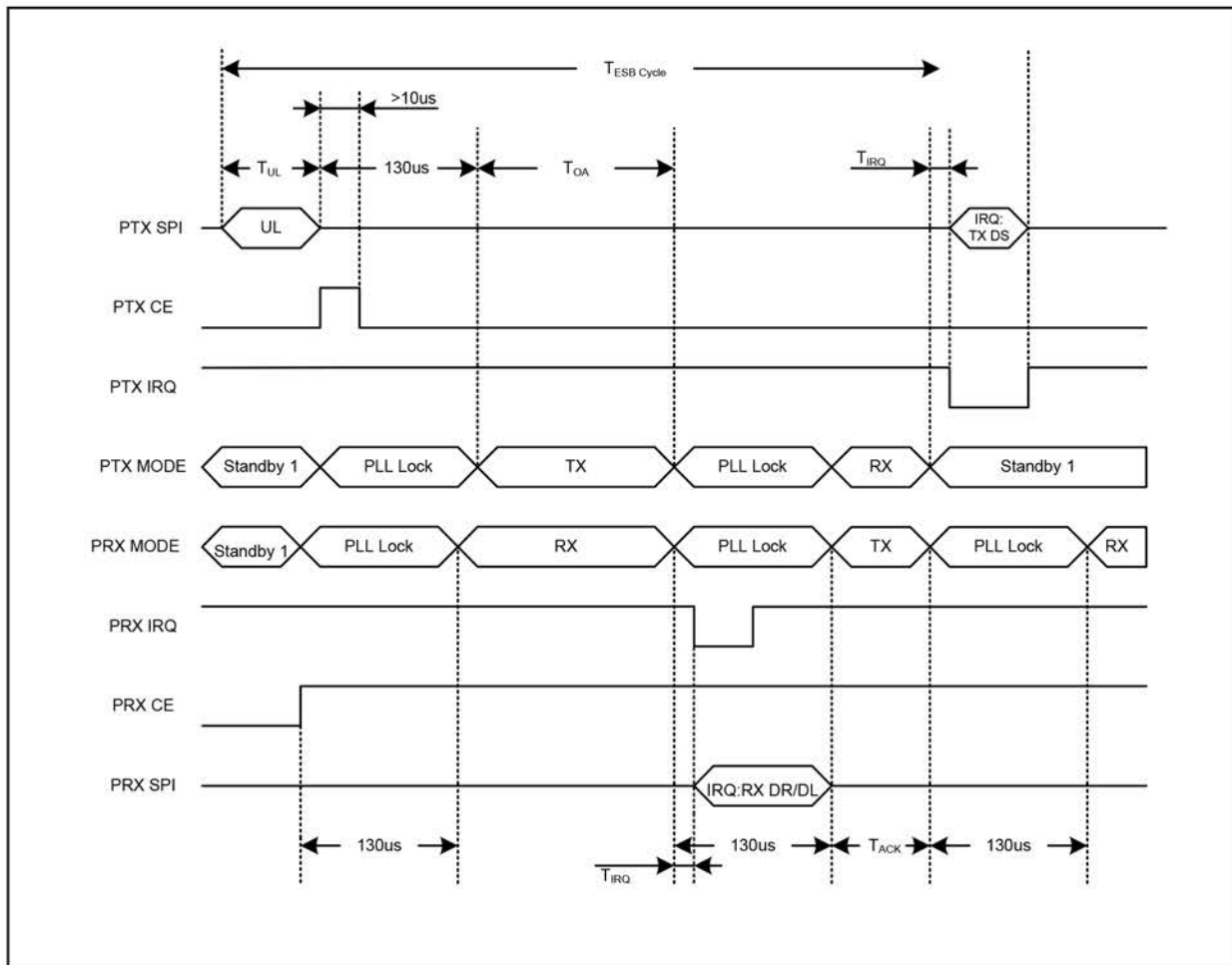


Figure 14. Timing of Enhanced ShockBurst™ for one packet upload (2Mbps)

In Figure 14. the transmission and acknowledgement of a packet is shown. The PRX device activates RX mode (CE=1), and the PTX device is activated in TX mode (CE=1 for minimum 10µs). After 130µs the transmission starts and finishes after the elapse of T_{OA} . When the transmission ends the PTX device automatically switches to RX mode to wait for the ACK packet from the PRX device. When the PRX device receives the packet it sets the interrupt for the host MCU and switches to TX mode to send an ACK. After the PTX device receives the ACK packet it sets the interrupt to the MCU and clears the packet from the TX FIFO.

7.9 Enhanced ShockBurst™ transaction diagram

This section describes several scenarios for the Enhanced ShockBurst™ automatic transaction handling. The call outs in this section's figures indicate the IRQs and other events. For MCU activity the event may be placed at a different timeframe.

Note: The figures in this section indicate the earliest possible download (DL) of the packet to the MCU and the latest possible upload (UL) of payload to the transmitter.

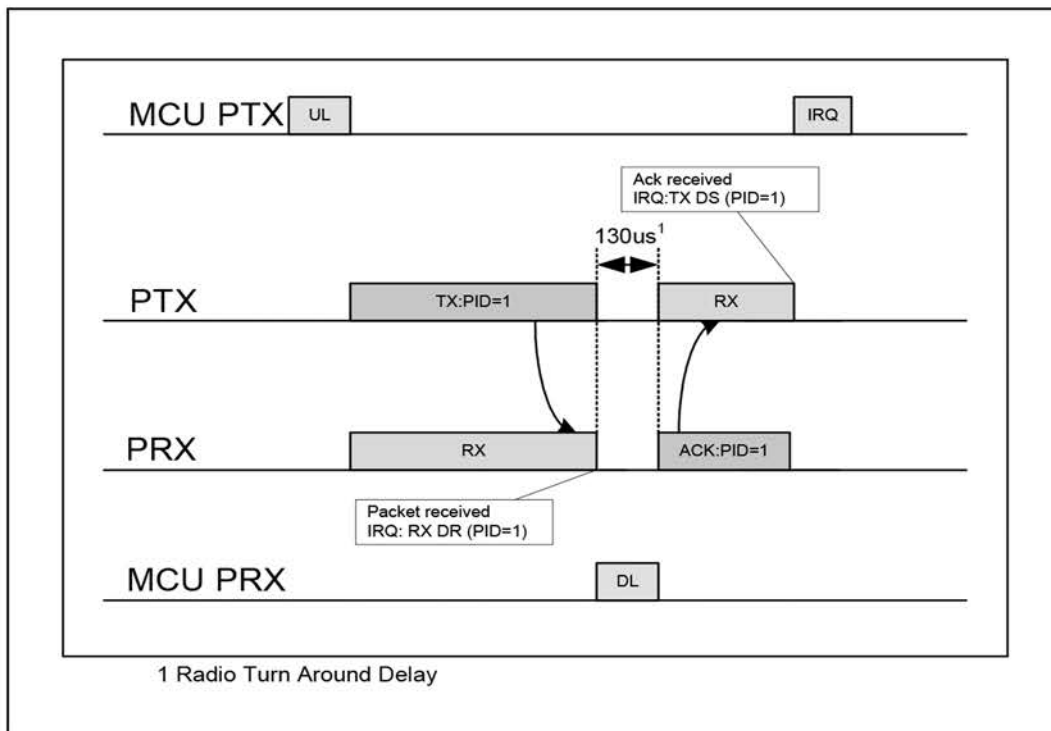


Figure 15. TX/RX cycles with ACK and the according interrupts

7.9.2 Single transaction with a lost packet

Figure 16. is a scenario where a retransmission is needed due to loss of the first packet transmit. After the packet is transmitted, the PTX enters RX mode to receive the ACK packet. After the first transmission, the PTX waits a specified time for the ACK packet, if it is not in the specific time slot the PTX retransmits the packet as shown in Figure 16.

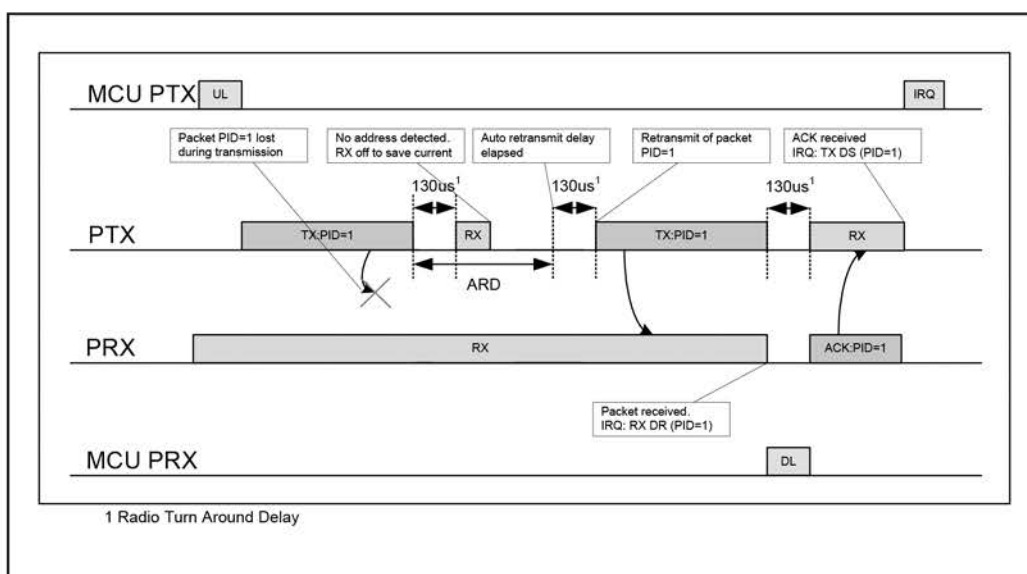


Figure 16. TX/RX cycles with ACK and the according interrupts when the first packet transmit fails

When an address is detected the PTX stays in RX mode until the packet is received. When the retransmitted packet is received by the PRX (see Figure 16.), the RX_DR IRQ is asserted and an ACK is transmitted back to the PTX. When the ACK is received by the PTX, the TX_DS IRQ is asserted.

7.9.3 Single transaction with a lost ACK packet

Figure 17. is a scenario where a retransmission is needed after a loss of the ACK packet. The corresponding interrupts are also indicated.

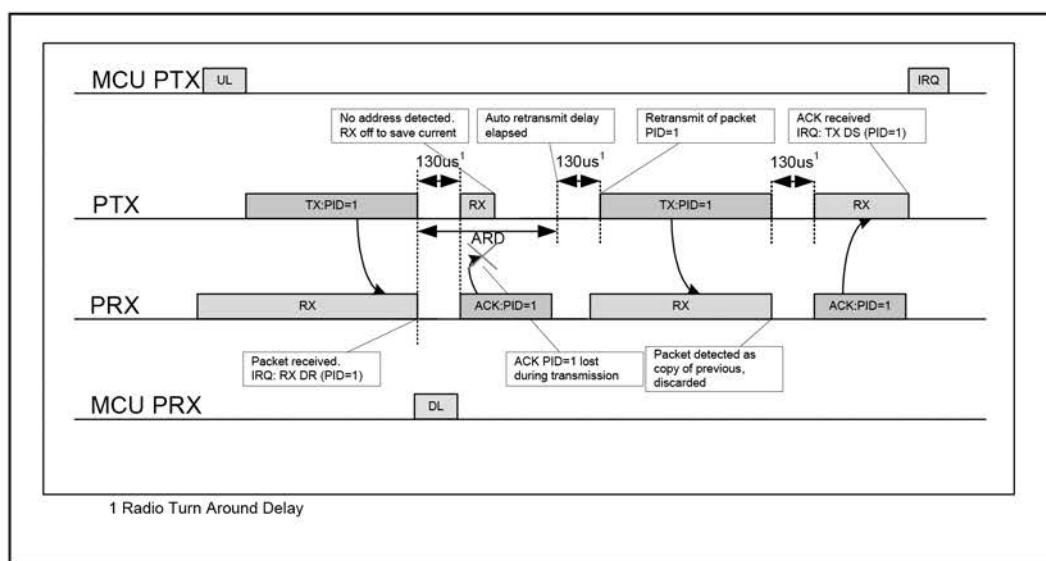


Figure 17. TX/RX cycles with ACK and the according interrupts when the ACK packet fails

7.9.4 Single transaction with ACK payload packet

Figure 18. is a scenario of the basic auto acknowledgement with payload. After the packet is transmitted by the PTX and received by the PRX the ACK packet with payload is transmitted from the PRX to the PTX. The RX_DR IRQ is asserted after the packet is received by the PRX, whereas on the PTX side the TX_DS IRQ is asserted when the ACK packet is received by the PTX. On the PRX side, the TX_DS IRQ for the ACK packet payload is asserted after a new packet from PTX is received. The position of the IRQ in Figure 18. shows where the MCU can respond to the interrupt.

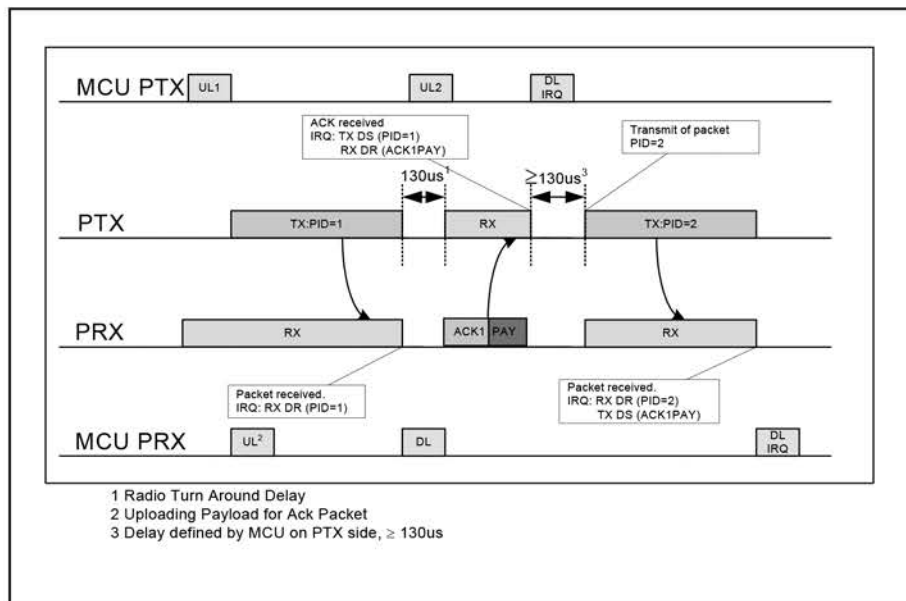


Figure 18. TX/RX cycles with ACK Payload and the according interrupts

7.9.5 Single transaction with ACK payload packet and lost packet

Figure 19. is a scenario where the first packet is lost and a retransmission is needed before the RX_DR IRQ on the PRX side is asserted. For the PTX both the TX_DS and RX_DR IRQ are asserted after the ACK packet is received. After the second packet (PID=2) is received on the PRX side both the RX_DR (PID=2) and TX_DS (ACK packet payload) IRQ are asserted.

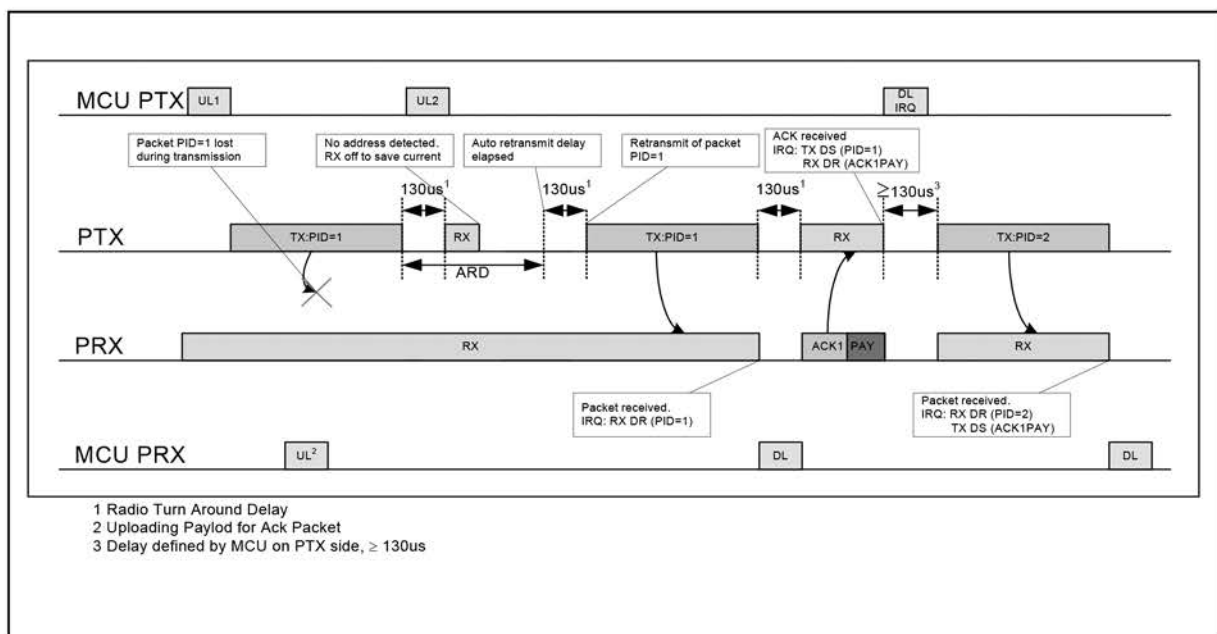


Figure 19. TX/RX cycles and the according interrupts when the packet transmission fails

7.9.6 Two transactions with ACK payload packet and the first ACK packet lost

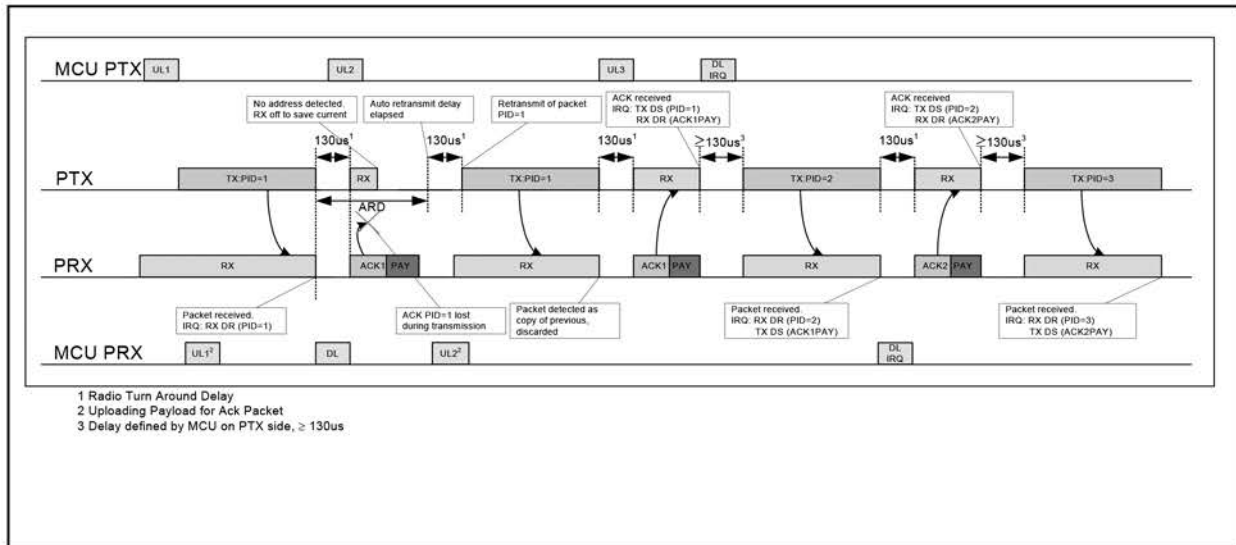


Figure 20. TX/RX cycles with ACK Payload and the according interrupts when the ACK packet fails

In Figure 20. the ACK packet is lost and a retransmission is needed before the TX_DS IRQ is asserted, but the RX_DR IRQ is asserted immediately. The retransmission of the packet (PID=1) results in a discarded packet. For the PTX both the TX_DS and RX_DR IRQ are asserted after the second transmission of ACK, which is received. After the second packet (PID=2) is received on the PRX both the RX_DR (PID=2) and TX_DS (ACK1PAY) IRQ is asserted. The callouts explain the different events and interrupts.

7.9.7 Two transactions where max retransmissions is reached

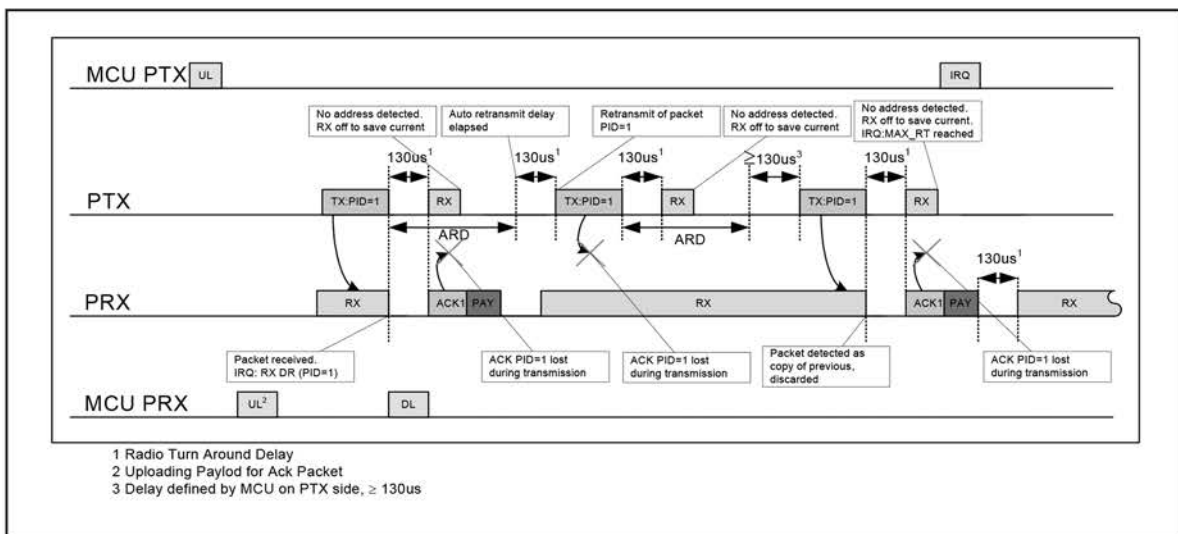


Figure 21. TX/RX cycles with ACK Payload and the according interrupts when the transmission fails. ARC is set to 2.

MAX_RT IRQ is asserted if the auto retransmit counter (ARC_CNT) exceeds the programmed maximum limit (ARC). In Figure 21. the packet transmission ends with a MAX_RT IRQ.

The payload in TX FIFO is NOT removed and the MCU decides the next step in the protocol. A toggle of the CE starts a new transmitting sequence of the same packet. The payload can be removed from the TX FIFO using the FLUSH_TX command.

7.10 Compatibility with ShockBurst™

You must disable Enhanced ShockBurst™ for backward compatibility with the nRF2401A, nRF2402, nRF24E1 and nRF24E2. Set the register EN_AA = 0x00 and ARC = 0 to disable Enhanced ShockBurst™. In addition, the nRF24L01+ air data rate must be set to 1Mbps or 250kbps.

7.10.1 ShockBurst™ packet format

Figure 22. shows the packet format with MSB to the left.



Figure 22. A ShockBurst™ packet compatible with nRF2401/nRF2402/nRF24E1/nRF24E2 devices.

The ShockBurst™ packet format has a preamble, address, payload and CRC field that are the same as the Enhanced ShockBurst™ packet format described in section 7.3.

The differences between the ShockBurst™ packet and the Enhanced ShockBurst™ packet are:

- The 9 bit Packet Control Field is not present in the ShockBurst™ packet format.
- The CRC is optional in the ShockBurst™ packet format and is controlled by the EN_CRC bit in the CONFIG register.

8. Data and Control Interface

The data and control interface gives you access to all the features in the nRF24L01+.

The data and control interface consists of the following six 5V tolerant digital signals:

- IRQ (this signal is active low and controlled by three maskable interrupt sources)
- CE (this signal is active high and used to activate the chip in RX or TX mode)
- CSN (SPI signal)
- SCK (SPI signal)
- MOSI (SPI signal)
- MISO (SPI signal)

Using 1 byte SPI commands, you can activate the nRF24L01+ data FIFOs or the register map during all modes of operation.

8.1 Features

- Special SPI commands for quick access to the most frequently used features
- 0-10Mbps 4-wire SPI
- 8 bit command set
- Easily configurable register map
- Full three level FIFO for both TX and RX direction

8.2 Functional description

The SPI is a standard SPI with a maximum data rate of 10Mbps.

8.3 SPI operation

This section describes the SPI commands and timing.

8.3.1 SPI Commands

The SPI commands are shown in Table 19. Every new command must be started by a high to low transition on CSN.

The STATUS register is serially shifted out on the MISO pin simultaneously to the SPI command word shifting to the MOSI pin.

The serial shifting SPI commands is in the following format:

<Command word: MSBit to LSBit (one byte)>

<Data bytes: LSByte to MSByte, MSBit in each byte first>

Command name	Command word (binary)	# Data bytes	Operation
R_REGISTER	000A AAAA	1 to 5 LSByte first	Read command and <i>status</i> registers. AAAAA = 5 bit Register Map Address
W_REGISTER	001A AAAA	1 to 5 LSByte first	Write command and status registers. AAAAA = 5 bit Register Map Address Executable in power down or standby modes only.
R_RX_PAYLOAD	0110 0001	1 to 32 LSByte first	Read RX-payload: 1 – 32 bytes. A read operation always starts at byte 0. Payload is deleted from FIFO after it is read. Used in RX mode.
W_TX_PAYLOAD	1010 0000	1 to 32 LSByte first	Write TX-payload: 1 – 32 bytes. A write operation always starts at byte 0 used in TX payload.
FLUSH_TX	1110 0001	0	Flush TX FIFO, used in TX mode
FLUSH_RX	1110 0010	0	Flush RX FIFO, used in RX mode Should not be executed during transmission of acknowledge, that is, acknowledge package will not be completed.
REUSE_TX_PL	1110 0011	0	Used for a PTX device Reuse last transmitted payload. TX payload reuse is active until W_TX_PAYLOAD or FLUSH TX is executed. TX payload reuse must not be activated or deactivated during package transmission.
R_RX_PL_WID ^a	0110 0000	1	Read RX payload width for the top R_RX_PAYLOAD in the RX FIFO.
W_ACK_PAYLOAD ^a	1010 1PPP	1 to 32 LSByte first	Used in RX mode. Write Payload to be transmitted together with ACK packet on PIPE PPP. (PPP valid in the range from 000 to 101). Maximum three ACK packet payloads can be pending. Payloads with same PPP are handled using first in - first out principle. Write payload: 1– 32 bytes. A write operation always starts at byte 0.
W_TX_PAYLOAD_NO_ACK ^a	1011 0000	1 to 32 LSByte first	Used in TX mode. Disables AUTOACK on this specific packet.
NOP	1111 1111	0	No Operation. Might be used to read the STATUS register

a. The bits in the FEATURE register shown in Table 27. have to be set.

Table 19. Command set for the nRF24L01+ SPI

The W_REGISTER and R_REGISTER commands operate on single or multi-byte registers. When accessing multi-byte registers read or write to the MSBit of LSByte first. You can terminate the writing before all bytes in a multi-byte register are written, leaving the unwritten MSByte(s) unchanged. For example, the LSByte of RX_ADDR_PO can be modified by writing only one byte to the RX_ADDR_PO register. The content of the status register is always read to MISO after a high to low transition on CSN.

Note: The 3 bit pipe information in the STATUS register is updated during the IRQ pin high to low transition. The pipe information is unreliable if the STATUS register is read during an IRQ pin high to low transition.

8.3.2 SPI timing

SPI operation and timing is shown in Figure 23. to Figure 25. and in Table 21. to Table 26.. nRF24L01+ must be in a standby or power down mode before writing to the configuration registers. In Figure 23. to Figure 25. the following abbreviations are used:

Abbreviation	Description
Cn	SPI command bit
Sn	STATUS register bit
Dn	Data Bit (Note: LSByte to MSByte, MSBit in each byte first)

Table 20. Abbreviations used in Figure 23. to Figure 25.

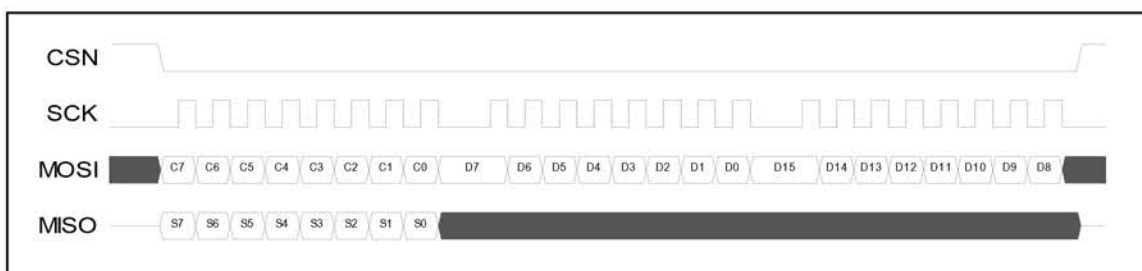


Figure 23. SPI read operation

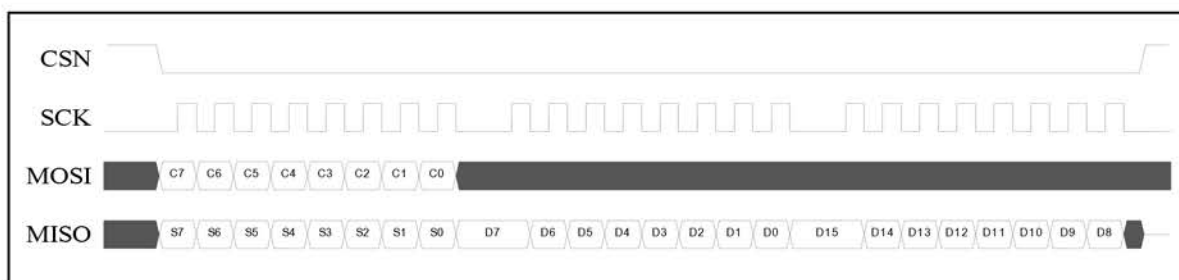


Figure 24. SPI write operation

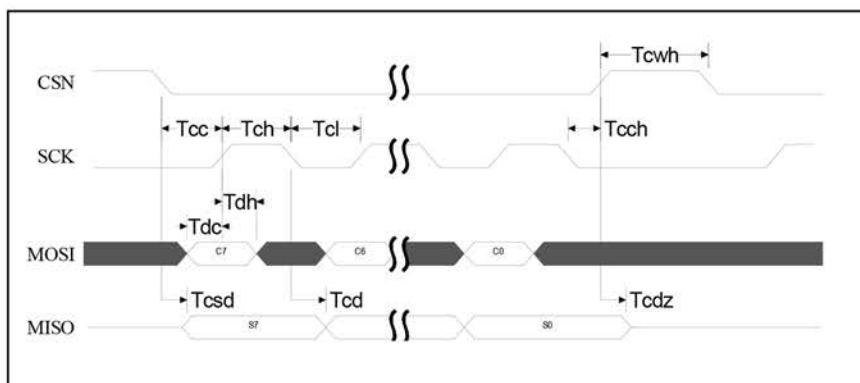


Figure 25. SPI NOP timing diagram

Figure 26. shows the R_{pull} and C_{load} that are referenced in Table 21. to Table 26.

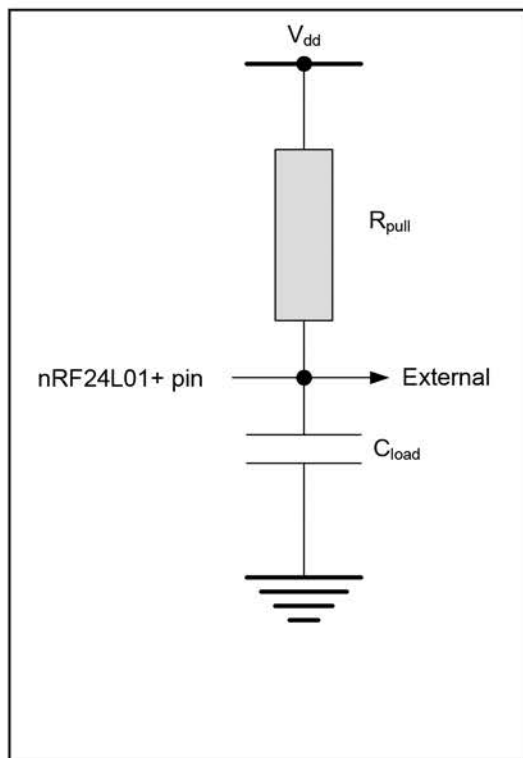


Figure 26. R_{pull} and C_{load}

Symbol	Parameters	Min.	Max	Units
Tdc	Data to SCK Setup	2		ns
Tdh	SCK to Data Hold	2		ns
Tcsd	CSN to Data Valid		38	ns
Tcd	SCK to Data Valid		55	ns
Tcl	SCK Low Time	40		ns
Tch	SCK High Time	40		ns
Fsck	SCK Frequency	0	10	MHz
Tr,Tf	SCK Rise and Fall		100	ns
Tcc	CSN to SCK Setup	2		ns
Tcch	SCK to CSN Hold	2		ns
Tcwh	CSN Inactive time	50		ns
Tcdz	CSN to Output High Z		38	ns

Table 21. SPI timing parameters ($C_{load} = 5pF$)

Symbol	Parameters	Min.	Max	Units
Tdc	Data to SCK Setup	2		ns
Tdh	SCK to Data Hold	2		ns
Tcsd	CSN to Data Valid		42	ns
Tcd	SCK to Data Valid		58	ns
Tcl	SCK Low Time	40		ns
Tch	SCK High Time	40		ns
Fsck	SCK Frequency	0	8	MHz
Tr,Tf	SCK Rise and Fall		100	ns
Tcc	CSN to SCK Setup	2		ns
Tcch	SCK to CSN Hold	2		ns
Tcwh	CSN Inactive time	50		ns
Tcdz	CSN to Output High Z		42	ns

Table 22. SPI timing parameters ($C_{load} = 10pF$)

Symbol	Parameters	Min.	Max	Units
Tdc	Data to SCK Setup	2		ns
Tdh	SCK to Data Hold	2		ns
Tcsd	CSN to Data Valid		75	ns
Tcd	SCK to Data Valid		86	ns
Tcl	SCK Low Time	40		ns
Tch	SCK High Time	40		ns
Fsck	SCK Frequency	0	5	MHz
Tr,Tf	SCK Rise and Fall		100	ns
Tcc	CSN to SCK Setup	2		ns
Tcch	SCK to CSN Hold	2		ns
Tcwh	CSN Inactive time	50		ns
Tcdz	CSN to Output High Z		75	ns

Table 23. SPI timing parameters ($R_{pull} = 10k\Omega$, $C_{load} = 50pF$)

Symbol	Parameters	Min.	Max	Units
Tdc	Data to SCK Setup	2		ns
Tdh	SCK to Data Hold	2		ns
Tcsd	CSN to Data Valid		116	ns
Tcd	SCK to Data Valid		123	ns
Tcl	SCK Low Time	40		ns
Tch	SCK High Time	40		ns
Fsck	SCK Frequency	0	4	MHz
Tr,Tf	SCK Rise and Fall		100	ns
Tcc	CSN to SCK Setup	2		ns
Tcch	SCK to CSN Hold	2		ns
Tcwh	CSN Inactive time	50		ns
Tcdz	CSN to Output High Z		116	ns

Table 24. SPI timing parameters ($R_{pull} = 10k\Omega$, $C_{load} = 100pF$)

Symbol	Parameters	Min.	Max	Units
Tdc	Data to SCK Setup	2		ns
Tdh	SCK to Data Hold	2		ns
Tcsd	CSN to Data Valid		75	ns
Tcd	SCK to Data Valid		85	ns
Tcl	SCK Low Time	40		ns
Tch	SCK High Time	40		ns
Fsck	SCK Frequency	0	5	MHz
Tr,Tf	SCK Rise and Fall		100	ns
Tcc	CSN to SCK Setup	2		ns
Tcch	SCK to CSN Hold	2		ns
Tcwh	CSN Inactive time	50		ns
Tcdz	CSN to Output High Z		75	ns

Table 25. SPI timing parameters ($R_{pull} = 50k\Omega$, $C_{load} = 50pF$)

Symbol	Parameters	Min.	Max	Units
Tdc	Data to sck Setup	2		ns
Tdh	sck to Data Hold	2		ns
Tcsd	csn to Data Valid		116	ns
Tcd	sck to Data Valid		121	ns
Tcl	sck Low Time	40		ns
Tch	sck High Time	40		ns
Fsck	sck Frequency	0	4	MHz
Tr, Tf	sck Rise and Fall		100	ns
Tcc	csn to sck Setup	2		ns
Toch	sck to csn Hold	2		ns
Tcwh	csn Inactive time	50		ns
Tcdz	csn to Output High Z		116	ns

Table 26. SPI timing parameters ($R_{pull} = 50k\Omega$, $C_{load} = 100pF$)

8.4 Data FIFO

The data FIFOs store transmitted payloads (TX FIFO) or received payloads that are ready to be clocked out (RX FIFO). The FIFOs are accessible in both PTX mode and PRX mode.

The following FIFOs are present in nRF24L01+:

- TX three level, 32 byte FIFO
- RX three level, 32 byte FIFO

Both FIFOs have a controller and are accessible through the SPI by using dedicated SPI commands. A TX FIFO in PRX can store payloads for ACK packets to three different PTX devices. If the TX FIFO contains more than one payload to a pipe, payloads are handled using the first in - first out principle. The TX FIFO in a PRX is blocked if all pending payloads are addressed to pipes where the link to the PTX is lost. In this case, the MCU can flush the TX FIFO using the FLUSH_TX command. The RX FIFO in PRX can contain payloads from up to three different PTX devices and a TX FIFO in PTX can have up to three payloads stored. You can write to the TX FIFO using these three commands; W_TX_PAYLOAD and W_TX_PAYLOAD_NO_ACK in PTX mode and W_ACK_PAYLOAD in PRX mode. All three commands provide access to the TX_PLD register (see Table 27., for details of this register). The RX FIFO can be read by the command R_RX_PAYLOAD in PTX and PRX mode. This command provides access to the RX_PLD register.

The payload in TX FIFO in a PTX is not removed if the MAX_RT IRQ is asserted.

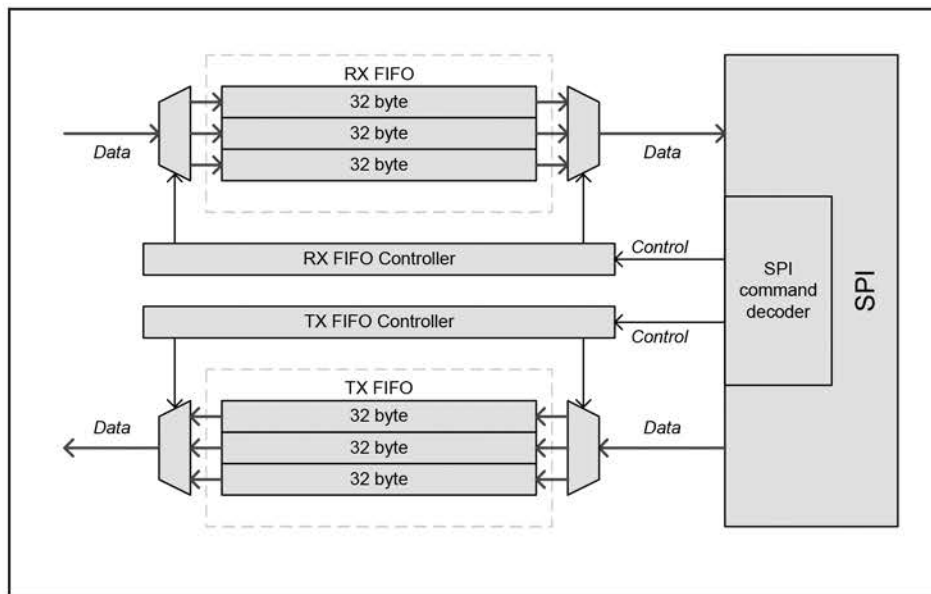


Figure 27. FIFO (RX and TX) block diagram

You can read if the TX and RX FIFO are full or empty in the FIFO_STATUS register.

8.5 Interrupt

The nRF24L01+ has an active low interrupt (IRQ) pin. The IRQ pin is activated when TX_DS IRQ, RX_DR IRQ or MAX_RT IRQ are set high by the state machine in the STATUS register. The IRQ pin resets when MCU writes '1' to the IRQ source bit in the STATUS register. The IRQ mask in the CONFIG register is used to select the IRQ sources that are allowed to assert the IRQ pin. By setting one of the MASK bits high, the corresponding IRQ source is disabled. By default all IRQ sources are enabled.

Note: The 3 bit pipe information in the STATUS register is updated during the IRQ pin high to low transition. The pipe information is unreliable if the STATUS register is read during an IRQ pin high to low transition.

9. Register Map

You can configure and control the radio by accessing the register map through the SPI.

9.1 Register map table

All undefined bits in the table below are redundant. They are read out as '0'.

Note: Addresses 18 to 1B are reserved for test purposes, altering them makes the chip malfunction.

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
00	CONFIG				Configuration Register
	Reserved	7	0	R/W	Only '0' allowed
	MASK_RX_DR	6	0	R/W	Mask interrupt caused by RX_DR 1: Interrupt not reflected on the IRQ pin 0: Reflect RX_DR as active low interrupt on the IRQ pin
	MASK_TX_DS	5	0	R/W	Mask interrupt caused by TX_DS 1: Interrupt not reflected on the IRQ pin 0: Reflect TX_DS as active low interrupt on the IRQ pin
	MASK_MAX_RT	4	0	R/W	Mask interrupt caused by MAX_RT 1: Interrupt not reflected on the IRQ pin 0: Reflect MAX_RT as active low interrupt on the IRQ pin
	EN_CRC	3	1	R/W	Enable CRC. Forced high if one of the bits in the EN_AA is high
	CRCO	2	0	R/W	CRC encoding scheme '0' - 1 byte '1' - 2 bytes
	PWR_UP	1	0	R/W	1: POWER UP, 0: POWER DOWN
	PRIM_RX	0	0	R/W	RX/TX control 1: PRX, 0: PTX
01	EN_AA Enhanced ShockBurst™				Enable 'Auto Acknowledgment' Function Disable this functionality to be compatible with nRF2401, see page 61
	Reserved	7:6	00	R/W	Only '00' allowed
	ENAA_P5	5	1	R/W	Enable auto acknowledgement data pipe 5
	ENAA_P4	4	1	R/W	Enable auto acknowledgement data pipe 4
	ENAA_P3	3	1	R/W	Enable auto acknowledgement data pipe 3
	ENAA_P2	2	1	R/W	Enable auto acknowledgement data pipe 2
	ENAA_P1	1	1	R/W	Enable auto acknowledgement data pipe 1
	ENAA_P0	0	1	R/W	Enable auto acknowledgement data pipe 0
02	EN_RXADDR				Enabled RX Addresses
	Reserved	7:6	00	R/W	Only '00' allowed
	ERX_P5	5	0	R/W	Enable data pipe 5.
	ERX_P4	4	0	R/W	Enable data pipe 4.
	ERX_P3	3	0	R/W	Enable data pipe 3.
	ERX_P2	2	0	R/W	Enable data pipe 2.

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
	ERX_P1	1	1	R/W	Enable data pipe 1.
	ERX_P0	0	1	R/W	Enable data pipe 0.
03	SETUP_AW				Setup of Address Widths (common for all data pipes)
	Reserved	7:2	000000	R/W	Only '000000' allowed
	AW	1:0	11	R/W	RX/TX Address field width '00' - Illegal '01' - 3 bytes '10' - 4 bytes '11' - 5 bytes LSByte is used if address width is below 5 bytes
04	SETUP_RETR				Setup of Automatic Retransmission
	ARD ^a	7:4	0000	R/W	Auto Retransmit Delay '0000' - Wait 250µS '0001' - Wait 500µS '0010' - Wait 750µS '1111' - Wait 4000µS (Delay defined from end of transmission to start of next transmission) ^b
	ARC	3:0	0011	R/W	Auto Retransmit Count '0000' - Re-Transmit disabled '0001' - Up to 1 Re-Transmit on fail of AA '1111' - Up to 15 Re-Transmit on fail of AA
05	RF_CH				RF Channel
	Reserved	7	0	R/W	Only '0' allowed
	RF_CH	6:0	0000010	R/W	Sets the frequency channel nRF24L01+ operates on
06	RF_SETUP				RF Setup Register
	CONT_WAVE	7	0	R/W	Enables continuous carrier transmit when high.
	Reserved	6	0	R/W	Only '0' allowed
	RF_DR_LOW	5	0	R/W	Set RF Data Rate to 250kbps. See RF_DR_HIGH for encoding.
	PLL_LOCK	4	0	R/W	Force PLL lock signal. Only used in test
	RF_DR_HIGH	3	1	R/W	Select between the high speed data rates. This bit is don't care if RF_DR_LOW is set. Encoding: [RF_DR_LOW, RF_DR_HIGH]: '00' - 1Mbps '01' - 2Mbps '10' - 250kbps '11' - Reserved

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
	RF_PWR	2:1	11	R/W	Set RF output power in TX mode '00' – -18dBm '01' – -12dBm '10' – -6dBm '11' – 0dBm
	Obsolete	0			Don't care
07	STATUS				Status Register (In parallel to the SPI command word applied on the MOSI pin, the STATUS register is shifted serially out on the MISO pin)
	Reserved	7	0	R/W	Only '0' allowed
	RX_DR	6	0	R/W	Data Ready RX FIFO interrupt. Asserted when new data arrives RX FIFO ^c . Write 1 to clear bit.
	TX_DS	5	0	R/W	Data Sent TX FIFO interrupt. Asserted when packet transmitted on TX. If AUTO_ACK is activated, this bit is set high only when ACK is received. Write 1 to clear bit.
	MAX_RT	4	0	R/W	Maximum number of TX retransmits interrupt Write 1 to clear bit. If MAX_RT is asserted it must be cleared to enable further communication.
	RX_P_NO	3:1	111	R	Data pipe number for the payload available for reading from RX_FIFO 000-101: Data Pipe Number 110: Not Used 111: RX FIFO Empty
	TX_FULL	0	0	R	TX FIFO full flag. 1: TX FIFO full. 0: Available locations in TX FIFO.
08	OBSERVE_TX				Transmit observe register
	PLOS_CNT	7:4	0	R	Count lost packets. The counter is overflow protected to 15, and discontinues at max until reset. The counter is reset by writing to RF_CH . See page 72 .
	ARC_CNT	3:0	0	R	Count retransmitted packets. The counter is reset when transmission of a new packet starts. See page 72 .
09	RPD				
	Reserved	7:1	000000	R	
	RPD	0	0	R	Received Power Detector. This register is called CD (Carrier Detect) in the nRF24L01. The name is different in nRF24L01+ due to the different input power level threshold for this bit. See section 6.4 on page 24 .
0A	RX_ADDR_P0	39:0	0xE7E7E7E7	R/W	Receive address data pipe 0. 5 Bytes maximum length. (LSByte is written first. Write the number of bytes defined by SETUP_AW)

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
0B	RX_ADDR_P1	39:0	0xC2C2C2C2C2C2	R/W	Receive address data pipe 1. 5 Bytes maximum length. (LSByte is written first. Write the number of bytes defined by SETUP_AW)
0C	RX_ADDR_P2	7:0	0xC3	R/W	Receive address data pipe 2. Only LSB. MSBytes are equal to RX_ADDR_P1[39:8]
0D	RX_ADDR_P3	7:0	0xC4	R/W	Receive address data pipe 3. Only LSB. MSBytes are equal to RX_ADDR_P1[39:8]
0E	RX_ADDR_P4	7:0	0xC5	R/W	Receive address data pipe 4. Only LSB. MSBytes are equal to RX_ADDR_P1[39:8]
0F	RX_ADDR_P5	7:0	0xC6	R/W	Receive address data pipe 5. Only LSB. MSBytes are equal to RX_ADDR_P1[39:8]
10	TX_ADDR	39:0	0xE7E7E7E7E7E7	R/W	Transmit address. Used for a PTX device only. (LSByte is written first) Set RX_ADDR_P0 equal to this address to handle automatic acknowledge if this is a PTX device with Enhanced ShockBurst™ enabled. See page 72 .
11	RX_PW_P0				
	Reserved	7:6	00	R/W	Only '00' allowed
	RX_PW_P0	5:0	0	R/W	Number of bytes in RX payload in data pipe 0 (1 to 32 bytes). 0 Pipe not used 1 = 1 byte ... 32 = 32 bytes
12	RX_PW_P1				
	Reserved	7:6	00	R/W	Only '00' allowed
	RX_PW_P1	5:0	0	R/W	Number of bytes in RX payload in data pipe 1 (1 to 32 bytes). 0 Pipe not used 1 = 1 byte ... 32 = 32 bytes
13	RX_PW_P2				
	Reserved	7:6	00	R/W	Only '00' allowed
	RX_PW_P2	5:0	0	R/W	Number of bytes in RX payload in data pipe 2 (1 to 32 bytes). 0 Pipe not used 1 = 1 byte ... 32 = 32 bytes
14	RX_PW_P3				
	Reserved	7:6	00	R/W	Only '00' allowed

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
	RX_PW_P3	5:0	0	R/W	Number of bytes in RX payload in data pipe 3 (1 to 32 bytes). 0 Pipe not used 1 = 1 byte ... 32 = 32 bytes
15	RX_PW_P4				
	Reserved	7:6	00	R/W	Only '00' allowed
	RX_PW_P4	5:0	0	R/W	Number of bytes in RX payload in data pipe 4 (1 to 32 bytes). 0 Pipe not used 1 = 1 byte ... 32 = 32 bytes
16	RX_PW_P5				
	Reserved	7:6	00	R/W	Only '00' allowed
	RX_PW_P5	5:0	0	R/W	Number of bytes in RX payload in data pipe 5 (1 to 32 bytes). 0 Pipe not used 1 = 1 byte ... 32 = 32 bytes
17	FIFO_STATUS				FIFO Status Register
	Reserved	7	0	R/W	Only '0' allowed
	TX_REUSE	6	0	R	Used for a PTX device Pulse the <code>rfce</code> high for at least 10µs to Reuse last transmitted payload. TX payload reuse is active until <code>w_tx_payload</code> or <code>FLUSH TX</code> is executed. <code>TX_REUSE</code> is set by the SPI command <code>REUSE_TX_PL</code> , and is reset by the SPI commands <code>w_tx_payload</code> or <code>FLUSH TX</code>
	TX_FULL	5	0	R	TX FIFO full flag. 1: TX FIFO full. 0: Available locations in TX FIFO.
	TX_EMPTY	4	1	R	TX FIFO empty flag. 1: TX FIFO empty. 0: Data in TX FIFO.
	Reserved	3:2	00	R/W	Only '00' allowed
	RX_FULL	1	0	R	RX FIFO full flag. 1: RX FIFO full. 0: Available locations in RX FIFO.
	RX_EMPTY	0	1	R	RX FIFO empty flag. 1: RX FIFO empty. 0: Data in RX FIFO.

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
N/A	ACK_PLD	255:0	X	W	Written by separate SPI command ACK packet payload to data pipe number PPP given in SPI command. Used in RX mode only. Maximum three ACK packet payloads can be pending. Payloads with same PPP are handled first in first out.
N/A	TX_PLD	255:0	X	W	Written by separate SPI command TX data payload register 1 - 32 bytes. This register is implemented as a FIFO with three levels. Used in TX mode only.
N/A	RX_PLD	255:0	X	R	Read by separate SPI command. RX data payload register. 1 - 32 bytes. This register is implemented as a FIFO with three levels. All RX channels share the same FIFO.
1C					
	DYNPD				Enable dynamic payload length
	Reserved	7:6	0	R/W	Only '00' allowed
	DPL_P5	5	0	R/W	Enable dynamic payload length data pipe 5. (Requires EN_DPL and ENAA_P5)
	DPL_P4	4	0	R/W	Enable dynamic payload length data pipe 4. (Requires EN_DPL and ENAA_P4)
	DPL_P3	3	0	R/W	Enable dynamic payload length data pipe 3. (Requires EN_DPL and ENAA_P3)
	DPL_P2	2	0	R/W	Enable dynamic payload length data pipe 2. (Requires EN_DPL and ENAA_P2)
	DPL_P1	1	0	R/W	Enable dynamic payload length data pipe 1. (Requires EN_DPL and ENAA_P1)
	DPL_P0	0	0	R/W	Enable dynamic payload length data pipe 0. (Requires EN_DPL and ENAA_P0)
1D					
	FEATURE			R/W	Feature Register
	Reserved	7:3	0	R/W	Only '00000' allowed
	EN_DPL	2	0	R/W	Enables Dynamic Payload Length
	EN_ACK_PAY ^d	1	0	R/W	Enables Payload with ACK
	EN_DYN_ACK	0	0	R/W	Enables the W_TX_PAYLOAD_NOACK command

a. Please take care when setting this parameter. If the ACK payload is more than 15 byte in 2Mbps mode the ARD must be 500µS or more, if the ACK payload is more than 5byte in 1Mbps mode the ARD must be 500µS or more. In 250kbps mode (even when the payload is not in ACK) the ARD must be 500µS or more.

b. This is the time the PTX is waiting for an ACK packet before a retransmit is made. The PTX is in RX mode for a minimum of 250µS, but it stays in RX mode to the end of the packet if that is longer than 250µS. Then it goes to standby-I mode for the rest of the specified ARD. After the ARD it goes to TX mode and then retransmits the packet.

c. The RX_DR IRQ is asserted by a new packet arrival event. The procedure for handling this interrupt should be: 1) read payload through SPI, 2) clear RX_DR IRQ, 3) read FIFO_STATUS to check if there are more payloads available in RX FIFO, 4) if there are more data in RX FIFO, repeat from step 1).

d. If ACK packet payload is activated, ACK packets have dynamic payload lengths and the Dynamic Payload Length feature should be enabled for pipe 0 on the PTX and PRX. This is to ensure that they receive the ACK packets with payloads. If the ACK payload is more than 15 byte in 2Mbps mode the ARD must be 500µS or more, and if the ACK payload is more than 5 byte in 1Mbps mode the ARD must be 500µS or more. In 250kbps mode (even when the payload is not in ACK) the ARD must be 500µS or more.

Table 27. Register map of nRF24L01+

10. Peripheral RF Information

This chapter describes peripheral circuitry and PCB layout requirements that are important for achieving optimum RF performance from the nRF24L01+.

10.1 Antenna output

The ANT1 and ANT2 output pins provide a balanced RF output to the antenna. The pins must have a DC path to V_{DD_PA}, either through a RF choke or through the center point in a balanced dipole antenna. A load of 15Ω+j88Ω is recommended for maximum output power (0dBm). Lower load impedance (for instance, 50Ω) can be obtained by fitting a simple matching network between the load and ANT1 and ANT2. A recommended matching network for 50Ω load impedance is described in chapter 11.

10.2 Crystal oscillator

A crystal used with the nRF24L01+ must fulfil the specifications in Table 11.

To achieve a crystal oscillator solution with low power consumption and fast start up time use a crystal with a low load capacitance specification. A lower CO also gives lower current consumption and faster start up time, but can increase the cost of the crystal. Typically CO=1.5pF at a crystal specified for COmax=7.0pF.

The crystal load capacitance, C_L, is given by:

$$C_L = \frac{C_1 \cdot C_2'}{C_1 + C_2'}, \text{ where } C_1' = C_1 + C_{PCB1} + C_{I1} \text{ and } C_2' = C_2 + C_{PCB2} + C_{I2}$$

C₁ and C₂ are SMD capacitors, see the application schematics in Figure 29. C_{PCB1} and C_{PCB2} are the layout parasitic on the circuit board. C_{I1} and C_{I2} are the internal capacitance load of the XC1 and XC2 pins respectively; the value is typically 1pF for both these pins.

10.3 nRF24L01+ crystal sharing with an MCU

Follow the rules described in sections 10.3.1 and 10.3.2 when using an MCU to drive the crystal reference input XC1 of the nRF24L01+ transceiver.

10.3.1 Crystal parameters

The MCU sets the requirement of load capacitance CL when it is driving the nRF24L01+ clock input. A frequency accuracy of $\pm 60\text{ppm}$ is required to get a functional radio link.

The nRF24L01+ loads the crystal by 1pF in addition to the PCB routing.

10.3.2 Input crystal amplitude and current consumption

The input signal should not have amplitudes exceeding any rail voltage. Exceeding rail voltage excites the ESD structure and consequently, the radio performance degrades below specification. You must use an external DC block if you are testing the nRF24L01+ with a reference source that has no DC offset (which is usual with a RF source).

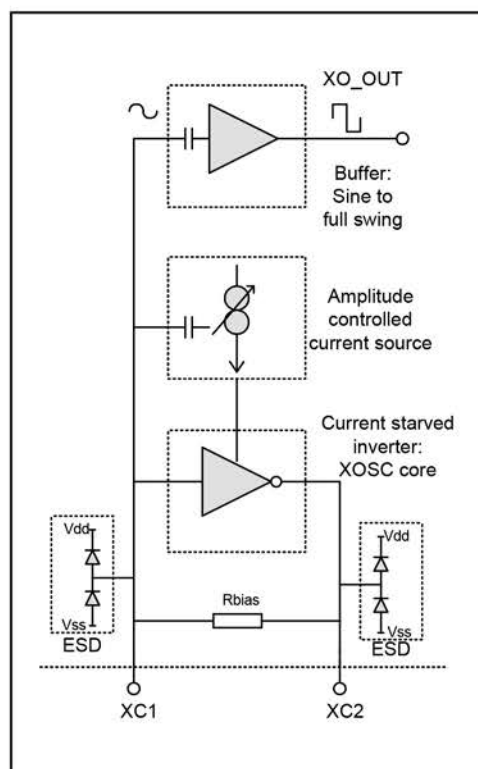


Figure 28. Principle of crystal oscillator

The nRF24L01+ crystal oscillator is amplitude regulated. It is recommended to use an input signal larger than 0.4V-peak to achieve low current consumption and good signal-to-noise ratio when using an external clock. XC2 is not used and can be left as an open pin when clocked externally.

10.4 PCB layout and decoupling guidelines

A well designed PCB is necessary to achieve good RF performance. A poor layout can lead to loss of performance or functionality. A PCB with a minimum of two layers including a ground plane is recommended for optimum performance. The nRF24L01+ DC supply voltage should be decoupled as close as possible to the V_{DD} pins with high performance RF capacitors, see Table 28. Mounting a large surface mount capacitor (for example, 4.7µF ceramic) in parallel with the smaller value capacitors is recommended. The nRF24L01+ supply voltage should be filtered and routed separately from the supply voltages of any digital circuitry. Avoid long power supply lines on the PCB. All device grounds, V_{DD} connections and V_{DD} bypass capacitors must be connected as close as possible to the nRF24L01+ IC. The V_{SS} pins should be connected directly to the ground plane for a PCB with a topside RF ground plane. We recommend having via holes as close as possible to the V_{SS} pads for a PCB with a bottom ground plane.

A minimum of one via hole should be used for each V_{SS} pin.

Full swing digital data or control signals should not be routed close to the crystal or the power supply lines.

The exposed die attach pad is a ground pad connected to the IC substrate die ground and is intentionally not used in our layouts. We recommend to keep it unconnected.

11. Application Example

nRF24L01+ with single ended matching network crystal, bias resistor, and decoupling capacitors.

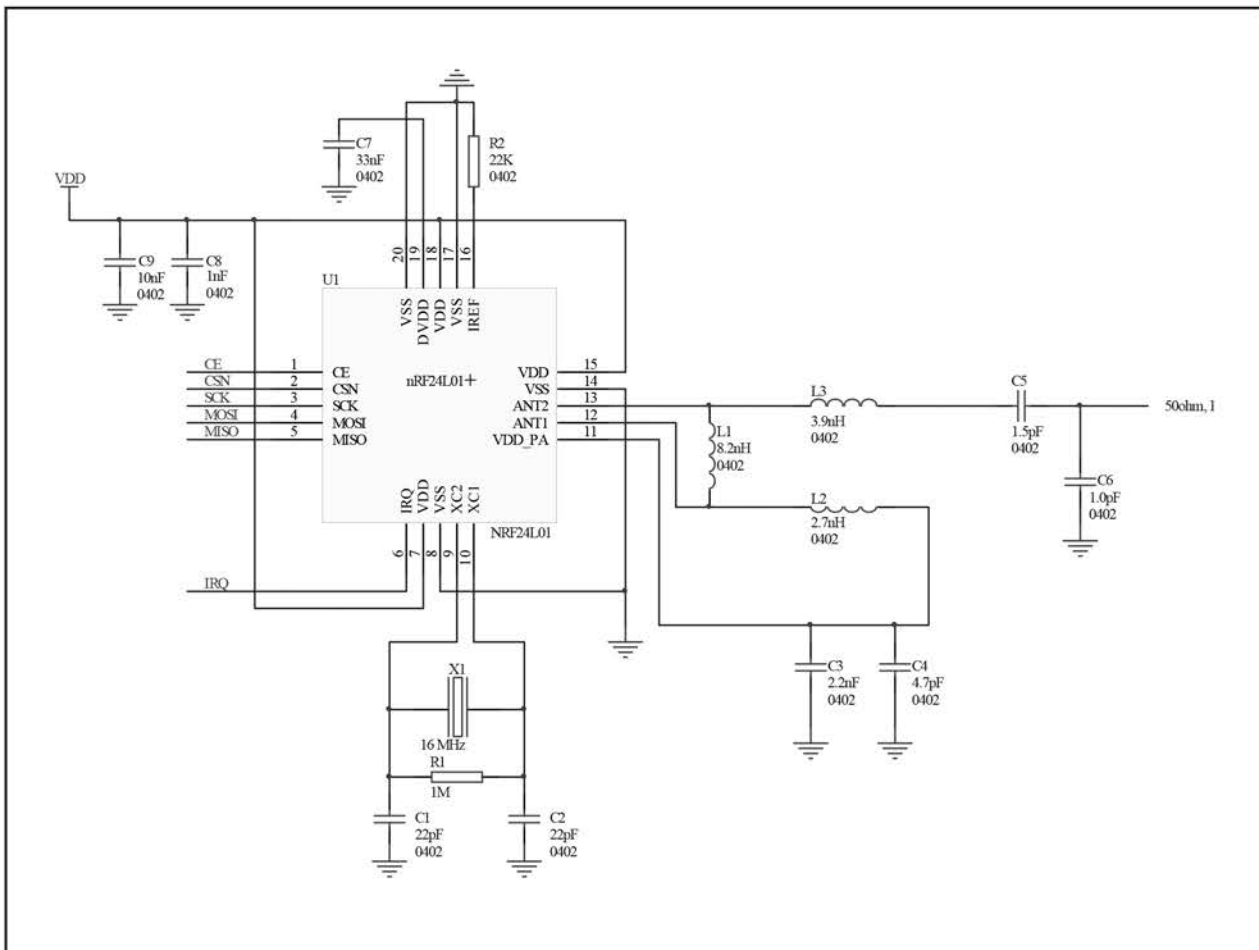


Figure 29. nRF24L01+ schematic for RF layouts with single ended 50Ω RF output

Part	Designator	Footprint	Description
22pF ^a	C1	0402	NPO, +/- 2%
22pF ^a	C2	0402	NPO, +/- 2%
2.2nF	C3	0402	X7R, +/- 10%
4.7pF	C4	0402	NPO, +/- 0.25pF
1.5pF	C5	0402	NPO, +/- 0.1pF
1,0pF	C6	0402	NPO, +/- 0.1pF
33nF	C7	0402	X7R, +/- 10%
1nF	C8	0402	X7R, +/- 10%
10nF	C9	0402	X7R, +/- 10%
8,2nH	L1	0402	chip inductor +/- 5%
2.7nH	L2	0402	chip inductor +/- 5%
3,9nH	L3	0402	chip inductor +/- 5%
Not mounted ^b	R1	0402	
22kΩ	R2	0402	+/-1%
nRF24L01+	U1	QFN20 4x4	
16MHz	X1		+/-60ppm, C _L =12pF

a. C1 and C2 must have values that match the crystals load capacitance, CL.

b. The nRF24L01+ and nRF24L01 application example and BOM are the same with the exception of R1. R1 can be mounted for backward compatibility with nRF24L01. The use of a 1Mohm resistor externally does not have any impact on crystal performance.

Table 28. Recommended components (BOM) in nRF24L01+ with antenna matching network

11.1 PCB layout examples

Figure 30., Figure 31. and Figure 32. show a PCB layout example for the application schematic in Figure 29.

A double-sided FR-4 board of 1.6mm thickness is used. This PCB has a ground plane on the bottom layer. Additionally, there are ground areas on the component side of the board to ensure sufficient grounding of critical components. A large number of via holes connect the top layer ground areas to the bottom layer ground plane.

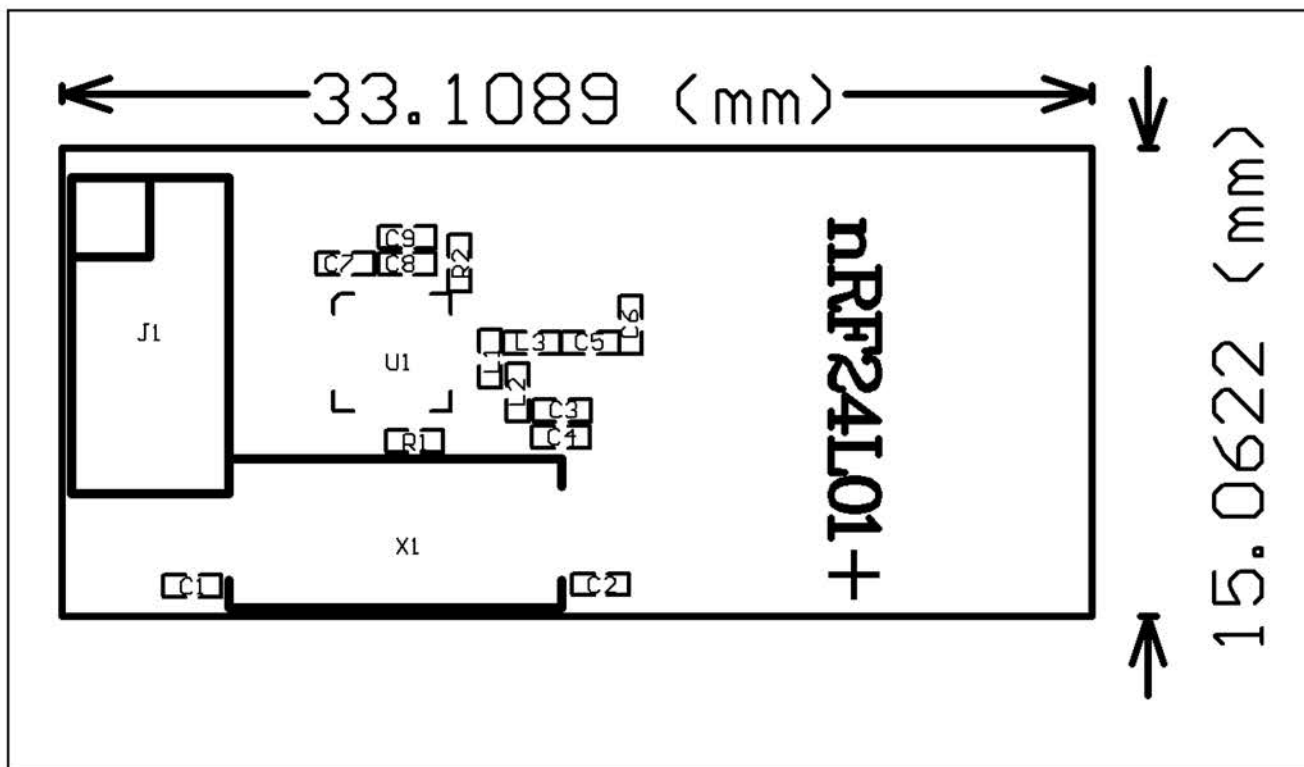


Figure 30. Top overlay (nRF24L01+ RF layout with single ended connection to PCB antenna and 0402 size passive components)

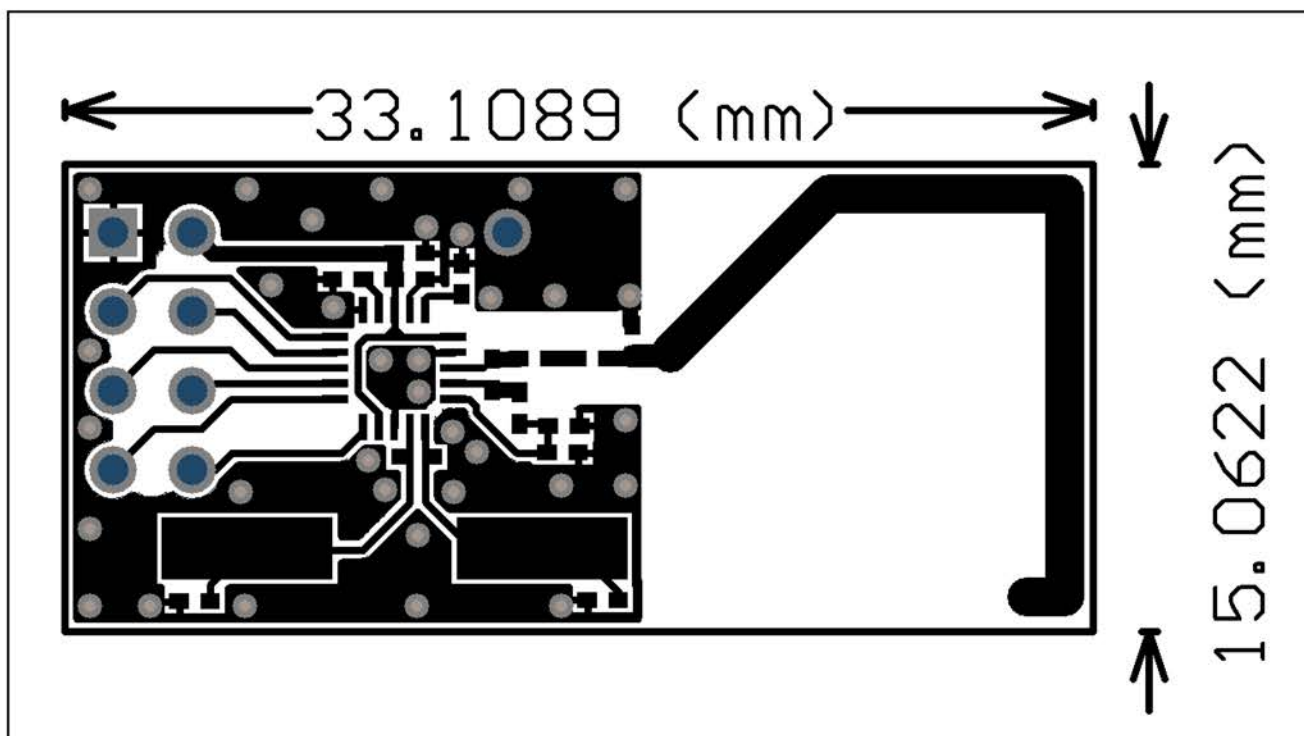


Figure 31. Top layer (nRF24L01+ RF layout with single ended connection to PCB antenna and 0402 size passive components)

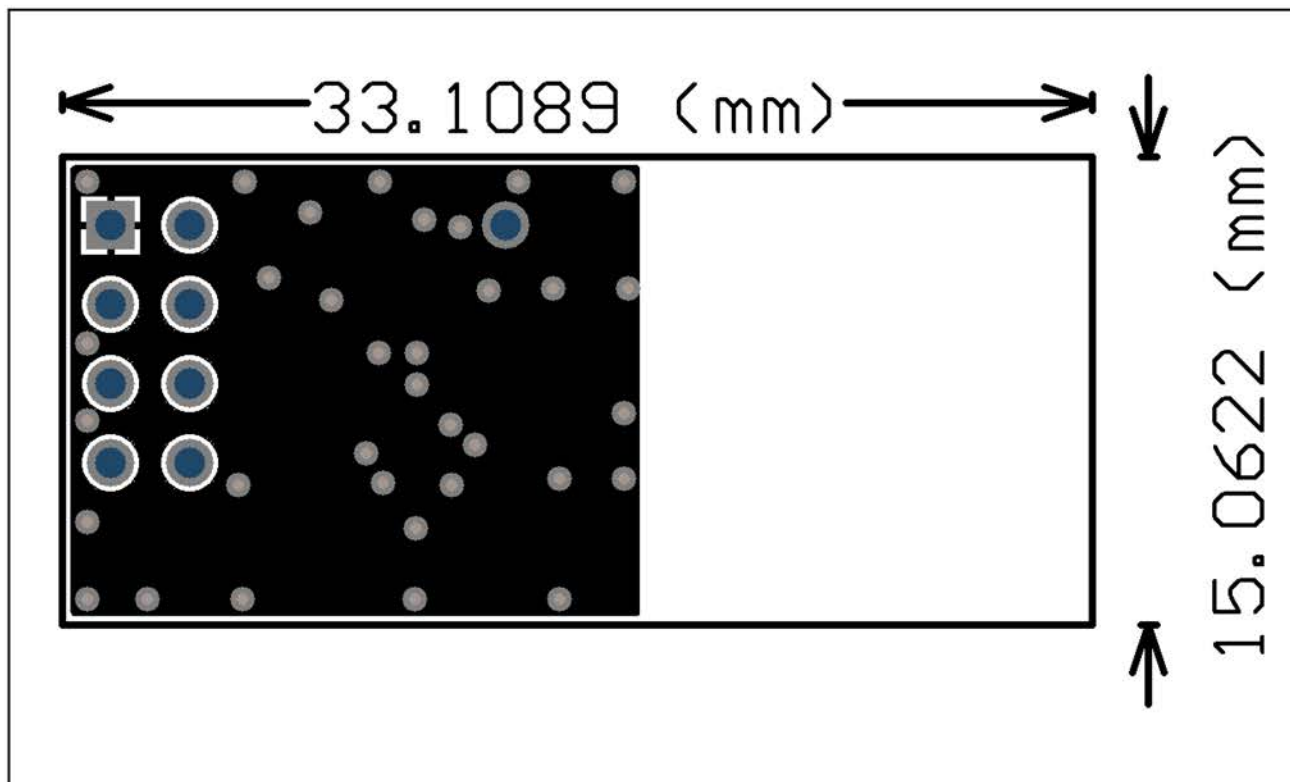


Figure 32. Bottom layer (nRF24L01+ RF layout with single ended connection to PCB antenna and 0402 size passive components)

The next figure (Figure 33., Figure 34. and Figure 35.) is for the SMA output to have a board for direct measurements at a 50Ω SMA connector.

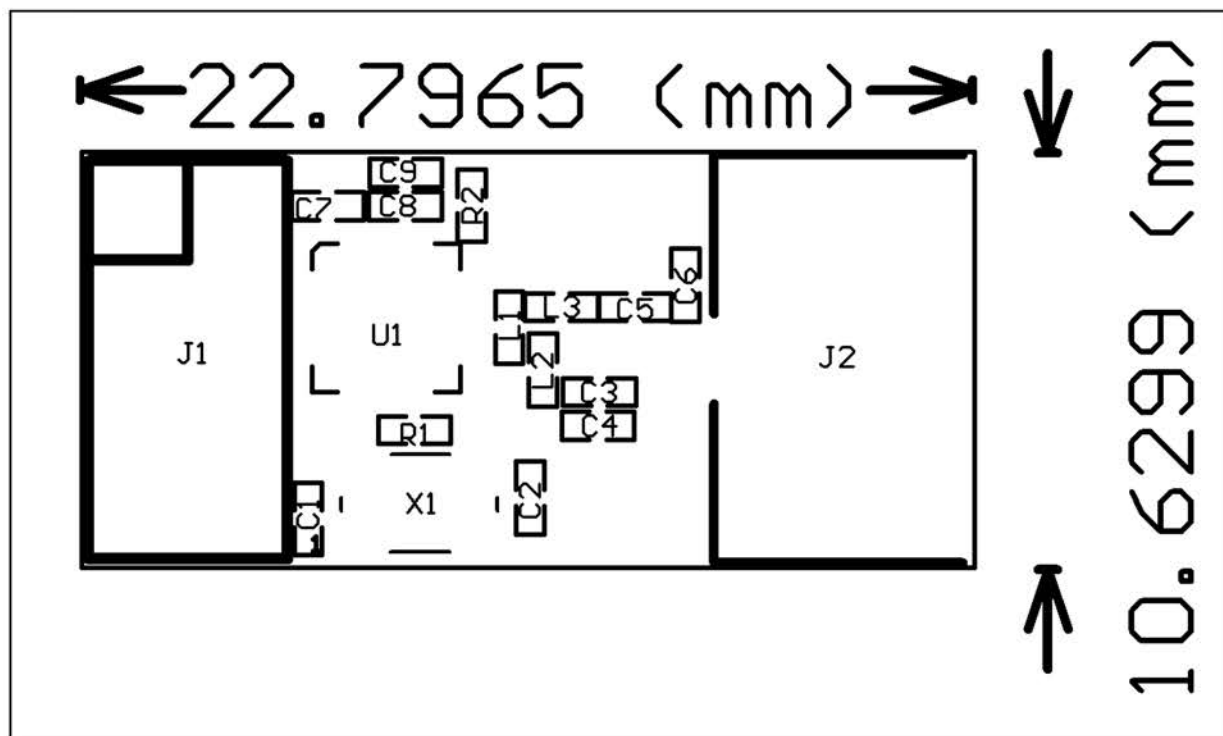


Figure 33. Top Overlay (Module with OFM crystal and SMA connector)

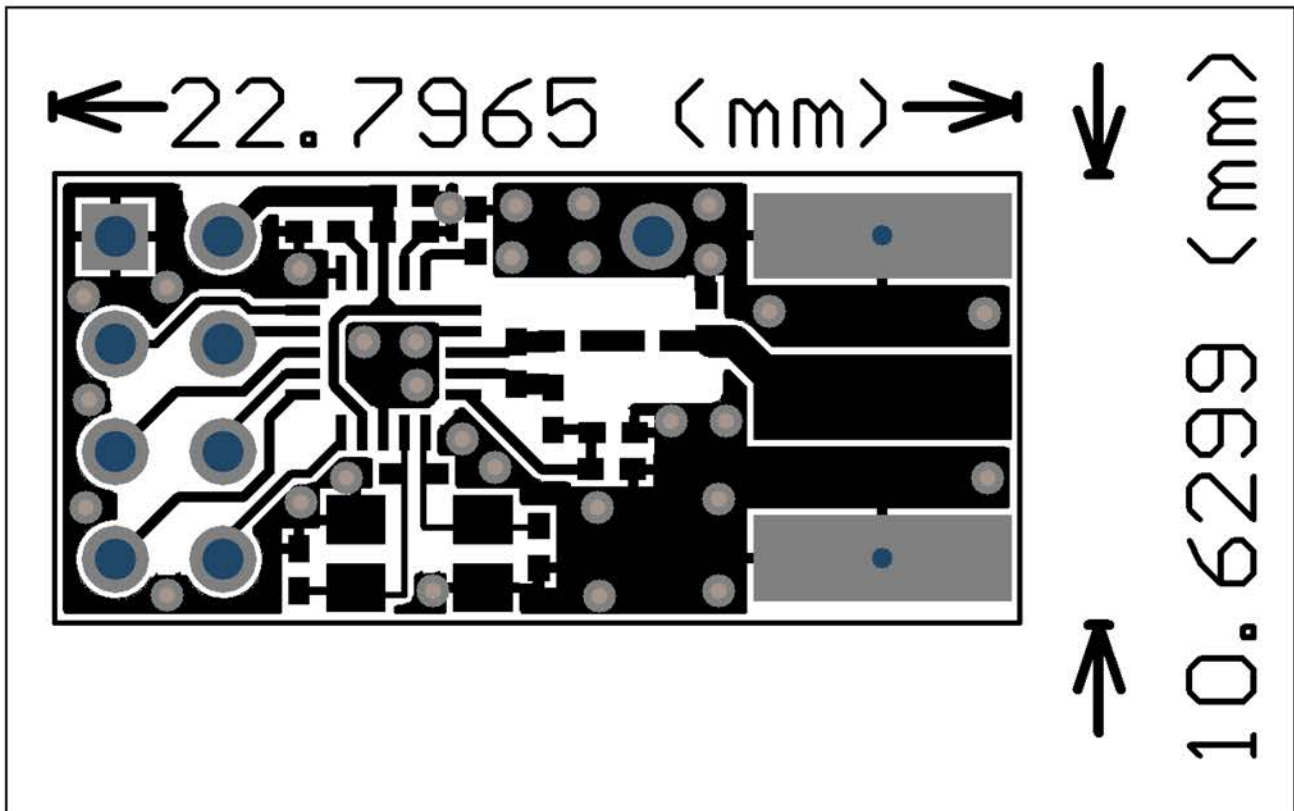


Figure 34. Top Layer (Module with OFM crystal and SMA connector)

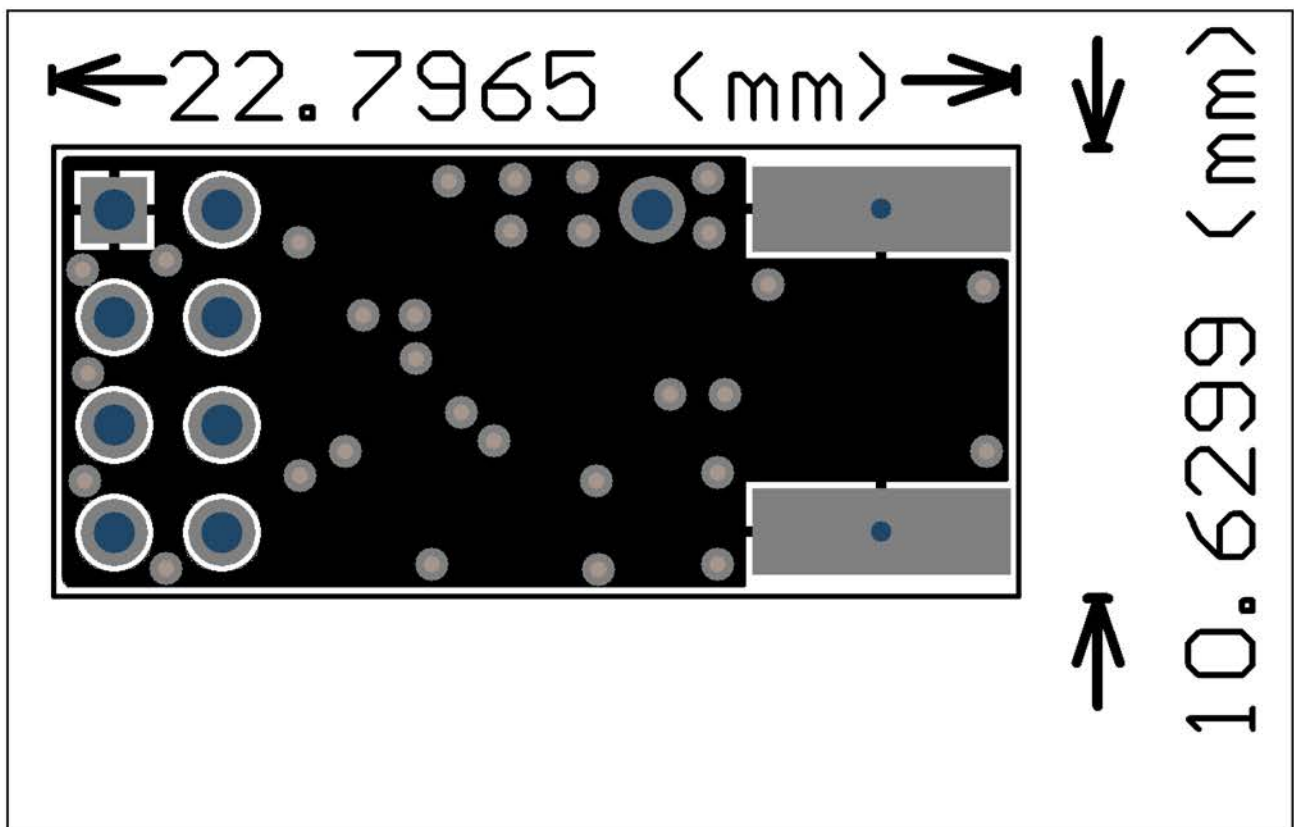
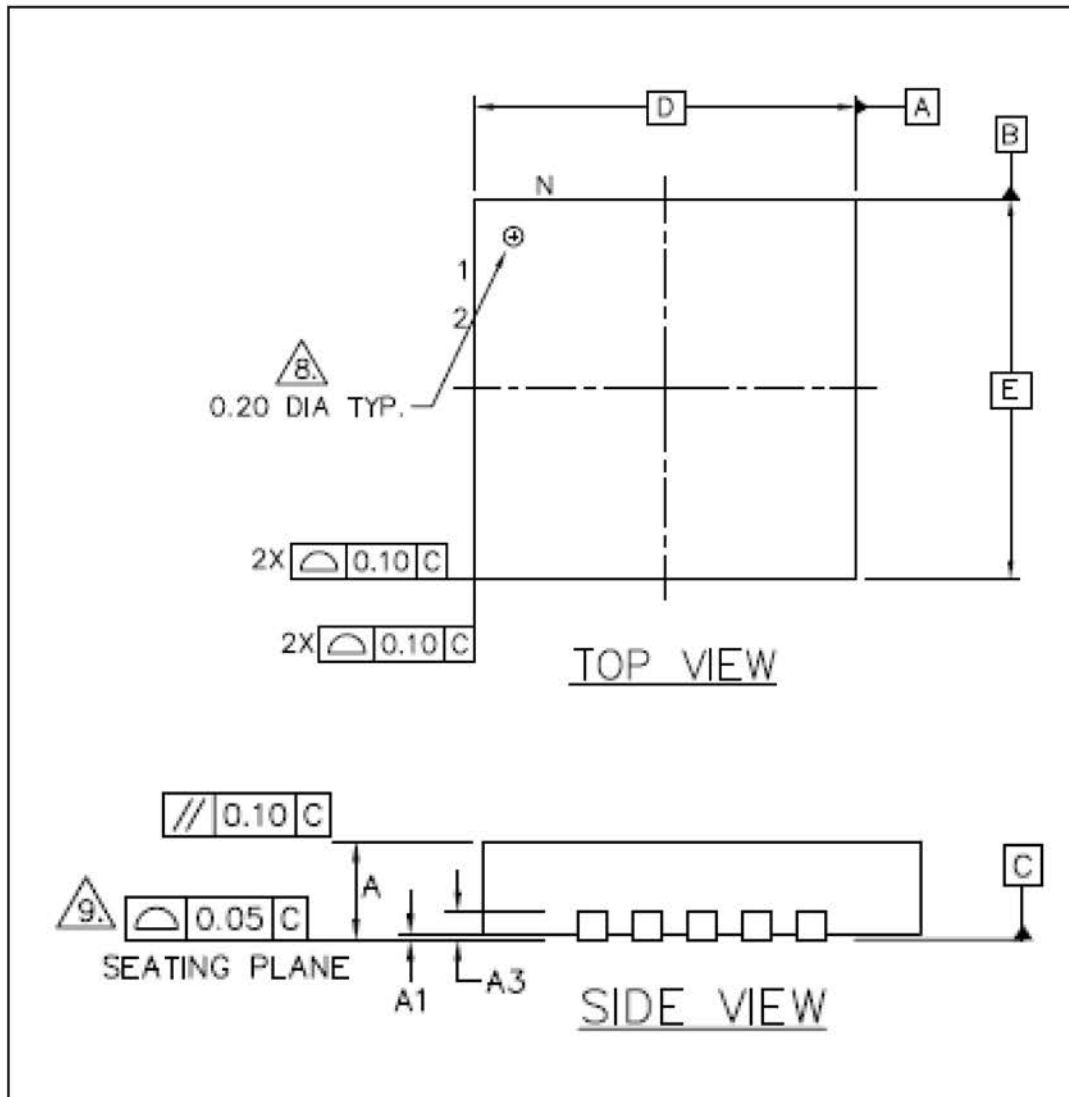
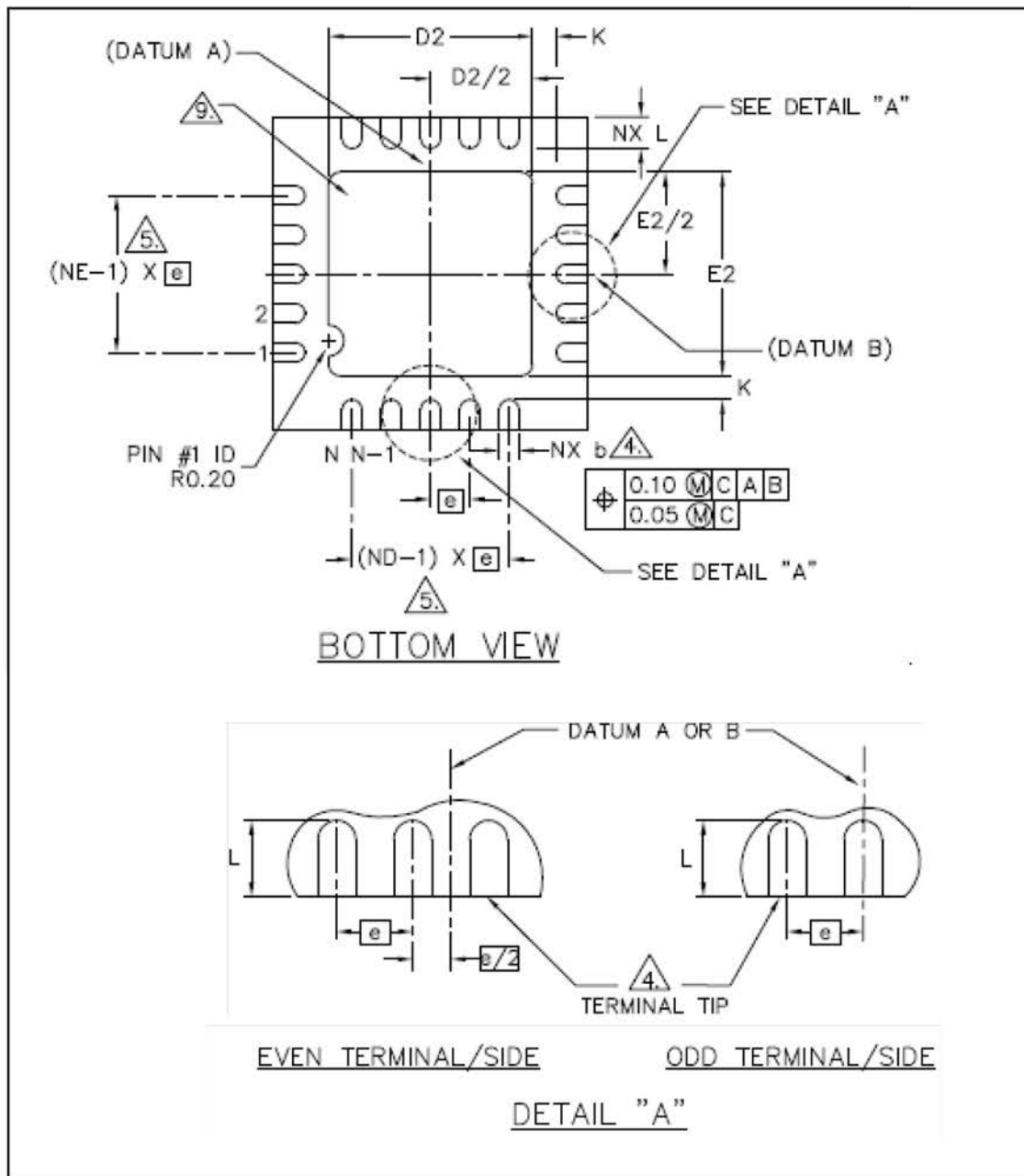


Figure 35. Bottom Layer (Module with OFM crystal and SMA connector)

12. Mechanical Specifications

nRF24L01+ uses the QFN20 4x4 package, with matt tin plating.





Package Type		A	A1	A3	K	D/E	e	D2/E2	L	L1	b
Saw QFN20 (4x4 mm)	Min.	0.80	0.00		0.20			2.50	0.35		0.18
	Typ.	0.85	0.02	0.20	0.20	4.0	0.5 BSC	2.60	0.40	0.15	0.25
	Max	0.95	0.05	REF.	min.	BSC ^a		2.70	0.45	max	0.30

a. BSC: Basic Spacing between Centers, ref. JEDEC standard 95, page 4.17-11/A

Figure 36. nRF24L01+ Package Outline

13. Appendix

Appendix A - Enhanced ShockBurst™ - Configuration and Communication Example Enhanced ShockBurst™ Transmitting Payload

1. Set the configuration bit PRIM_RX low.

2. When the application MCU has data to transmit, clock the address for the receiving node (TX_ADDR) and payload data (TX_PLD) into nRF24L01+ through the SPI. The width of TX-payload

is counted from the number of bytes written into the TX FIFO from the MCU. TX_PLD must be written continuously while holding CSN low. TX_ADDR does not have to be rewritten if it is unchanged from last transmit. If the PTX device shall receive acknowledge, configure data pipe 0 to receive the ACK packet. The RX address for data pipe 0 (RX_ADDR_P0) must be equal to the TX address (TX_ADDR) in the PTX device. For the example in Figure 12. perform the following address settings for the TX5 device and the RX device:

TX5 device: TX_ADDR = 0xB3B4B5B605

TX5 device: RX_ADDR_P0 = 0xB3B4B5B605

RX device: RX_ADDR_P5 = 0xB3B4B5B605

3. A high pulse on CE starts the transmission. The minimum pulse width on CE is 10µs.

4. nRF24L01+ ShockBurst™:

> Radio is powered up.

> 16MHz internal clock is started.

> RF packet is completed (see the packet description).

> Data is transmitted at high speed (1Mbps or 2Mbps configured by MCU).

5. If auto acknowledgement is activated (ENAA_P0=1) the radio goes into RX mode immediately, unless the NO_ACK bit is set in the received packet. If a valid packet is received in the valid acknowledgement time window, the transmission is considered a success. The TX_DS bit in the STATUS register is set high and the payload is removed from TX FIFO. If a valid ACK packet is not received in the specified time window, the payload is retransmitted (if auto retransmit is enabled). If the auto retransmit counter (ARC_CNT) exceeds the programmed maximum limit (ARC), the MAX_RT bit in the STATUS register is set high. The payload in TX FIFO is NOT removed. The IRQ pin is active when MAX_RT or TX_DS is high. To turn off the IRQ pin, reset the interrupt source by writing to the STATUS register (see Interrupt chapter). If no ACK packet is received for a packet after the maximum number of retransmits, no further packets can be transmitted before the MAX_RT interrupt is cleared. The packet loss counter (PLOS_CNT) is incremented at each MAX_RT interrupt. That is, ARC_CNT counts the number of retransmits that were required to get a single packet through. PLOS_CNT counts the number of packets that did not get through after the maximum number of retransmits.

6. nRF24L01+ goes into standby-I mode if CE is low. Otherwise, next payload in TX FIFO is transmitted. If TX FIFO is empty and CE is still high, nRF24L01+ enters standby-II mode.

7. If nRF24L01+ is in standby-II mode, it goes to standby-I mode immediately if CE is set low.

Enhanced ShockBurst™ Receive Payload

1. Select RX by setting the PRIM_RX bit in the CONFIG register to high. All data pipes that receive data must be enabled (EN_RXADDR register), enable auto acknowledgement for all pipes running Enhanced ShockBurst™ (EN_AA register), and set the correct payload widths (RX_PW_Px registers).

Set up addresses as described in item 2 in the Enhanced ShockBurst™ transmitting payload example above.

2. Start Active RX mode by setting CE high.

3. After 130µs nRF24L01+ monitors the air for incoming communication.

4. When a valid packet is received (matching address and correct CRC), the payload is stored in the RX-FIFO, and the RX_DR bit in STATUS register is set high. The IRQ pin is active when RX_DR is high. RX_P_NO in STATUS register indicates what data pipe the payload has been received in.

5. If auto acknowledgement is enabled, an ACK packet is transmitted back, unless the NO_ACK bit is set in the received packet. If there is a payload in the TX_PLD FIFO, this payload is added to the ACK packet.

6. MCU sets the CE pin low to enter standby-I mode (low current mode).

7. MCU can clock out the payload data at a suitable rate through the SPI.

8. nRF24L01+ is now ready for entering TX or RX mode or power down mode.

Appendix B - Configuration for compatibility with nRF24XX

How to setup nRF24L01+ to receive from an nRF2401/nRF2402/nRF24E1/nRF24E2:

1. Use the same CRC configuration as the nRF2401/nRF2402/nRF24E1/nRF24E2.
2. Set the PWR_UP and PRIM_RX bit to 1.
3. Disable auto acknowledgement on the data pipe that is addressed.
4. Use the same address width as the PTX device.
5. Use the same frequency channel as the PTX device.
6. Select data rate 1Mbps or 250kbps on both nRF24L01+ and nRF2401/nRF2402/nRF24E1/nRF24E2.
7. Set correct payload width on the data pipe that is addressed.
8. Set CE high.

How to setup nRF24L01+ to transmit to an nRF2401/nRF24E1:

1. Use the same CRC configuration as the nRF2401/nRF2402/nRF24E1/nRF24E2.
2. Set the PRIM_RX bit to 0.
3. Set the Auto Retransmit Count to 0 to disable the auto retransmit functionality.
4. Use the same address width as the nRF2401/nRF2402/nRF24E1/nRF24E2.
5. Use the same frequency channel as the nRF2401/nRF2402/nRF24E1/nRF24E2.
6. Select data rate 1Mbps or 250kbps on both nRF24L01+ and nRF2401/nRF2402/nRF24E1/nRF24E2.
7. Set PWR_UP high.
8. Clock in a payload that has the same length as the nRF2401/nRF2402/nRF24E1/nRF24E2 is configured to receive.
9. Pulse CE to transmit the packet.

Appendix C - Constant carrier wave output for testing

The output power of a radio is a critical factor for achieving wanted range. Output power is also the first test criteria needed to qualify for all telecommunication regulations.

Configuration

1. Set PWR_UP = 1 and PRIM_RX = 0 in the CONFIG register.
2. Wait 1.5ms PWR_UP→standby.
3. In the RF register set:
 - › CONT_WAVE = 1.
 - › PLL_LOCK = 1.
 - › RF_PWR.
4. Set the wanted RF channel.
5. Set CE high.
6. Keep CE high as long as the carrier is needed.

Note: Do not use REUSE_TX_PL together with CONT_WAVE=1. When both these registers are set the chip does not react when setting CE low. If however, both registers are set PWR_UP = 0 will turn TX mode off.

The nRF24L01+ should now output an unmodulated centered carrier.