

Single chip 2.4 GHz Transceiver

nRF24L01

FEATURES

- True single chip GFSK transceiver
- Complete OSI Link Layer in hardware
- Enhanced ShockBurst™
- Auto ACK & retransmit
- Address and CRC computation
- On the air data rate 1 or 2Mbps
- Digital interface (SPI) speed 0-10 Mbps
- 125 RF channel operation
- Short switching time enable frequency hopping
- Fully RF compatible with nRF24XX
- 5V tolerant signal input pads
- 20-pin package (QFN20 4x4mm)
- Uses ultra low cost +/- 60 ppm crystal
- Uses low cost chip inductors and 2-layer PCB
- Power supply range: 1.9 to 3.6 V

APPLICATIONS

- Wireless mouse, keyboard, joystick
- Keyless entry
- Wireless data communication
- Alarm and security systems
- Home automation
- Surveillance
- Automotive
- Telemetry
- Intelligent sports equipment
- Industrial sensors
- Toys

GENERAL DESCRIPTION

nRF24L01 is a single chip radio transceiver for the world wide 2.4 - 2.5 GHz ISM band. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, modulator and Enhanced ShockBurst™ protocol engine. Output power, frequency channels, and protocol setup are easily programmable through a SPI interface. Current consumption is very low, only 9.0mA at an output power of -6dBm and 12.3mA in RX mode. Built-in Power Down and Standby modes makes power saving easily realizable.

QUICK REFERENCE DATA

Parameter	Value	Unit
Minimum supply voltage	1.9	V
Maximum output power	0	dBm
Maximum data rate	2000	kbps
Supply current in TX mode @ 0dBm output power	11.3	mA
Supply current in RX mode @ 2000 kbps	12.3	mA
Temperature range	-40 to +85	°C
Sensitivity @ 1000 kbps	-85	dBm
Supply current in Power Down mode	900	nA

Table 1 nRF24L01 quick reference data



Type Number	Description	Version
nRF24L01	20 pin QFN 4x4, lead free (green)	A
nRF24L01 IC	Bare Dice	A
nRF24L01-EVKIT	Evaluation kit (2 test PCB, 2 configuration PCB, SW)	1.0

Table 2 nRF24L01 ordering information

PIN FUNCTIONS

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
7	VDD	Power	Power Supply (+3V 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 (+1.8V) to Power Amplifier
12	ANT1	RF	Antenna interface 1
13	ANT2	RF	Antenna interface 2
14	VSS	Power	Ground (0V)
15	VDD	Power	Power Supply (+3V DC)
16	IREF	Analog Input	Reference current
17	VSS	Power	Ground (0V)
18	VDD	Power	Power Supply (+3V DC)
19	DVDD	Power Output	Positive Digital Supply output for de-coupling purposes
20	VSS	Power	Ground (0V)

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



ELECTRICAL SPECIFICATIONS

Conditions: VDD = +3V, VSS = 0V, TA = - 40°C to + 85°C

Symbol	Parameter (condition)	Notes	Min.	Typ.	Max.	Units
Operating conditions						
VDD	Supply voltage		1.9	3.0	3.6	V
TEMP	Operating Temperature		-40	+27	+85	°C
Digital input pin						
V _{IH}	HIGH level input voltage	¹	0.7VDD		5.25	V
V _{IL}	LOW level input voltage		VSS		0.3VDD	V
Digital output pin						
V _{OH}	HIGH level output voltage (I _{OH} =-0.5mA)		VDD- 0.3		VDD	V
V _{OL}	LOW level output voltage (I _{OL} =0.5mA)		VSS		0.3	V
General RF conditions						
f _{OP}	Operating frequency	²	2400		2525	MHz
f _{XTAL}	Crystal frequency			16		MHz
Δf _{1M}	Frequency deviation @ 1000kbps			±160		kHz
Δf _{2M}	Frequency deviation @ 2000kbps			±320		kHz
R _{GFSK}	Data rate ShockBurst™		>0		2000	kbps
F _{CHANNEL}	Channel spacing @ 1000kbps			1		MHz
F _{CHANNEL}	Channel spacing @ 2000kbps			2		MHz
Transmitter operation						
P _{RF}	Maximum Output Power	³	0	+4		dBm
P _{RFC}	RF Power Control Range		16	18	20	dB
P _{RFCR}	RF Power Accuracy				±4	dB
P _{BW}	20dB Bandwidth for Modulated Carrier (2000kbps)				2000	kHz
P _{RF1}	1 st Adjacent Channel Transmit Power 2MHz				-20	dBm
P _{RF2}	2 nd Adjacent Channel Transmit Power 4MHz				-50	dBm
I _{VDD}	Supply current @ 0dBm output power	⁴	11.3			mA
I _{VDD}	Supply current @ -18dBm output power			7.0		mA
I _{VDD}	Average Supply current @ -6dBm output power, Enhanced ShockBurst™	⁵		0.05		mA
I _{VDD}	Supply current in Standby-I mode			32		μA
I _{VDD}	Supply current in power down			900		nA

¹ All digital inputs handle up to 5.25V signal inputs. Keep in mind that the VDD of the nRF24L01 must match the V_{IH} of the driving device for output pins.

PRELIMINARY PRODUCT SPECIFICATION



nRF24L01 Single Chip 2.4 GHz Radio Transceiver

²Usable band is determined by local regulations

³Antenna load impedance = $100\Omega + j175\Omega$

⁴Antenna load impedance = $100\Omega + j175\Omega$. Effective data rate 1000kbps or 2000 kbps

⁵Antenna load impedance = $100\Omega + j175\Omega$. Effective data rate 10kbps and full packets



Table 4 nRF24L01 RF specifications

Receiver operation						
I _{VDD}	Supply current one channel 2000kbps			12.3		mA
I _{VDD}	Supply current one channel 1000kbps			11.8		mA
RX _{SENS}	Sensitivity at 0.1%BER (@2000kbps)			-82		dBm
RX _{SENS}	Sensitivity at 0.1%BER (@1000kbps)			-85		dBm
C/I _{CO}	C/I Co-channel	⁶		5 ⁷ /12 ⁸		dB
C/I _{1ST}	1 st Adjacent Channel Selectivity C/I 2MHz			0/5		dB
C/I _{2ND}	2 nd Adjacent Channel Selectivity C/I 4MHz			-21/-19		dB
C/I _{3RD}	3 rd Adjacent Channel Selectivity C/I 6MHz			-27/-27		dB
C/I _{CO}	C/I Co-channel	⁹		7 ¹⁰ /14 ¹¹		dB
C/I _{1ST}	1 st Adjacent Channel Selectivity C/I 1MHz			6/10		dB
C/I _{2ND}	2 nd Adjacent Channel Selectivity C/I 2MHz			-22/-20		dB
C/I _{3RD}	3 rd Adjacent Channel Selectivity C/I 3MHz			-30/-25		dB

⁶ Data rate is 2000kbps for the following C/I measurements

⁷ According to ETSI EN 300 220-1 V1.3.1 (2000-09) page 36

⁸ nRF24L01 equal modulation on interfering signal

⁹ Data rate is 1000kbps for the following C/I measurements

¹⁰ According to ETSI EN 300 220-1 V1.3.1 (2000-09) page 36

¹¹ nRF24L01 equal modulation on interfering signal

PRELIMINARY PRODUCT SPECIFICATION



nRF24L01 Single Chip 2.4 GHz Radio Transceiver

Package Type		A	A1	A3	K	D/E	e	D2/E2	L	L1	b
Saw QFN20 (4x4 mm)	Min	0.80	0.00					2.50	0.35		0.18
	Typ.	0.85	0.02	0.20	0.20			2.60	0.40	0.15	0.25
	Max	0.95	0.05	REF.	min	4.0 BSC ¹²	0.5 BSC	2.70	0.45	max	0.30

Figure 3 nRF24L01 Package Outline.

¹²BSC: Basic Spacing between Centers, ref. JEDEC standard 95, page 4.17-11/A



Package marking:

n	R	F		B	X
D	D	D	D	D	D
Y	Y	W	W	L	L

Abbreviations:

DDDDDD	– Product number, e.g. 24L01
B	– Build Code, i.e. unique code for production sites, package type and test platform
X	– "X" grade, i.e. Engineering Samples (optional)
YY	– 2 digit Year number
WW	– 2 digit Week number
LL	– 2 letter wafer lot number code

Absolute Maximum Ratings

Supply voltages

VDD.....V to + 3.6V

VSS.....V

Input voltage

V_I.....V to 5.25V

Output voltage

V_O.....VSS to VDD

Total Power Dissipation

P_D(T_A=85°C).....60mW

Temperatures

Operating Temperature.... - 40°C to + 85°C

Storage Temperature..... - 40°C to + 125°C

Note: Stress exceeding one or more of the limiting values may cause permanent damage to the device.

ATTENTION!

Electrostatic Sensitive Device

Observe Precaution for handling.





Glossary of Terms

Term	Description
ACK	Acknowledgement
ART	Auto Re-Transmit
CE	Chip Enable
CLK	Clock
CRC	Cyclic Redundancy Check
CSN	Chip Select NOT
ESB	Enhanced ShockBurst™
GFSK	Gaussian Frequency Shift Keying
IRQ	Interrupt Request
ISM	Industrial-Scientific-Medical
LNA	Low Noise Amplifier
LSB	Least Significant Bit
LSByte	Least Significant Byte
Mbps	Megabit per second
MCU	Micro Controller Unit
MISO	Master In Slave Out
MOSI	Master Out Slave In
MSB	Most Significant Bit
MSByte	Most Significant Byte
PCB	Printed Circuit Board
PER	Packet Error Rate
PID	Packet Identity Bits
PLD	Payload
PRX	Primary RX
PTX	Primary TX
PWR_DWN	Power Down
PWR_UP	Power Up
RX	Receive
RX_DR	Receive Data Ready
SPI	Serial Peripheral Interface
TX	Transmit
TX_DS	Transmit Data Sent

Table 5 Glossary



FUNCTIONAL DESCRIPTION

Modes of operation

The nRF24L01 can be set in the following main modes depending on the level of the following primary I/Os and configuration registers:

Mode	PWR_UP register	PRIM_RX register	CE	FIFO state
RX mode	1	1	1	-
TX mode	1	0	1	Data in TX FIFO
TX mode	1	0	1 ^{€0}	Stays in TX mode until packet transmission is finished
Standby-II	1	0	1	TX FIFO empty
Standby-I	1	-	0	No ongoing packet transmission
Power Down	0	-	-	-

Table 6 nRF24L01 main modes

An overview of the nRF24L01 I/O pins in different modes is given in Table 7.

Pin functions in the different modes of nRF24L01

Pin Name	Direction	TX Mode	RX Mode	Standby Modes	Power Down
CE	Input	High Pulse >10µs	High	Low	-
CSN	Input		SPI Chip Select, active low		
SCK	Input		SPI Clock		
MOSI	Input		SPI Serial Input		
MISO	Tri-state Output		SPI Serial Output		
IRQ	Output		Interrupt, active low		

Table 7 Pin functions of the nRF24L01

Standby Modes

Standby-I mode is used to minimize average current consumption while maintaining short start up times. In this mode, part of the crystal oscillator is active. In Standby-II mode some clock buffers are active. Standby-II occurs when CE is held high on a PTX device with empty TX FIFO. The configuration word content is maintained during Standby modes. SPI interface may be activated. For start up time see Table 13.

Power Down Mode

In power down nRF24L01 is disabled with minimal current consumption. When entering this mode the device is not active, but all registers values available from the SPI interface are maintained during power down and the SPI interface may be activated (CSN=0). For start up time see Table 13. The power down is controlled by the PWR_UP bit in the CONFIG register.



Packet Handling Methods

nRF24L01 has the following Packet Handling Methods:

- ShockBurst™ (compatible with nRF2401, nRF24E1, nRF2402 and nRF24E2 with 1Mbps data rate, see page 24)
- Enhanced ShockBurst™

ShockBurst™

ShockBurst™ makes it possible to use the high data rate offered by nRF24L01 without the need of a costly, high-speed microcontroller (MCU) for data processing/clock recovery. By placing all high speed signal processing related to RF protocol on-chip, nRF24L01 offers the application microcontroller a simple SPI compatible interface, the data rate is decided by the interface-speed the micro controller itself sets up. By allowing the digital part of the application to run at low speed, while maximizing the data rate on the RF link, ShockBurst™ reduces the average current consumption in applications.

In ShockBurst™ RX, IRQ notifies the MCU when a valid address and payload is received respectively. The MCU can then clock out the received payload from an nRF24L01 RX FIFO.

In ShockBurst™ TX, nRF24L01 automatically generates preamble and CRC, see Table 12. IRQ notifies the MCU that the transmission is completed. All together, this means reduced memory demand in the MCU resulting in a low cost MCU, as well as reduced software development time. nRF24L01 has a three level deep RX FIFO (shared between 6 pipes) and a three level deep TX FIFO. The MCU can access the FIFOs at any time, in power down mode, in standby modes, and during RF packet transmission. This allows the slowest possible SPI interface compared to the average datarate, and may enable usage of an MCU without hardware SPI.

Enhanced ShockBurst™

Enhanced ShockBurst™ is a packet handling method with functionality that makes bi-directional link protocol implementation easier and more efficient. In a typical bi-directional link, one will let the terminating part acknowledge received packets from the originating part in order to make it possible to detect data loss. Data loss can then be recovered by retransmission. The idea with Enhanced ShockBurst™ is to let nRF24L01 handle both acknowledgement of received packets and retransmissions of lost packets, without involvement from the microcontroller.

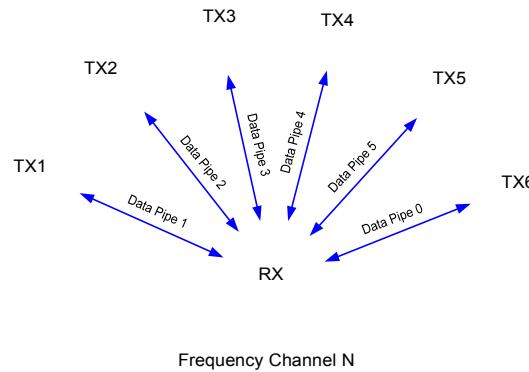


Figure 4: nRF24L01 in a star network configuration

An nRF24L01 configured as primary RX (PRX) will be able to receive data through 6 different data pipes, see Figure 4. A data pipe will have a unique address but share the same frequency channel. This means that up to 6 different nRF24L01 configured as primary TX (PTX) can communicate with one nRF24L01 configured as PRX, and the nRF24L01 configured as PRX will be able to distinguish between them. Data pipe 0 has a unique 40 bit configurable address. Each of data pipe 1-5 has an 8 bit unique address and shares the 32 most significant address bits. All data pipes can perform full Enhanced ShockBurst™ functionality.

nRF24L01 will use the data pipe address when acknowledging a received packet. This means that nRF24L01 will transmit ACK with the same address as it receives payload at. In the PTX device data pipe 0 is used to receive the acknowledge, and therefore the receive address for data pipe 0 has to be equal to the transmit address to be able to receive the acknowledge. See Figure 5 for addressing example.

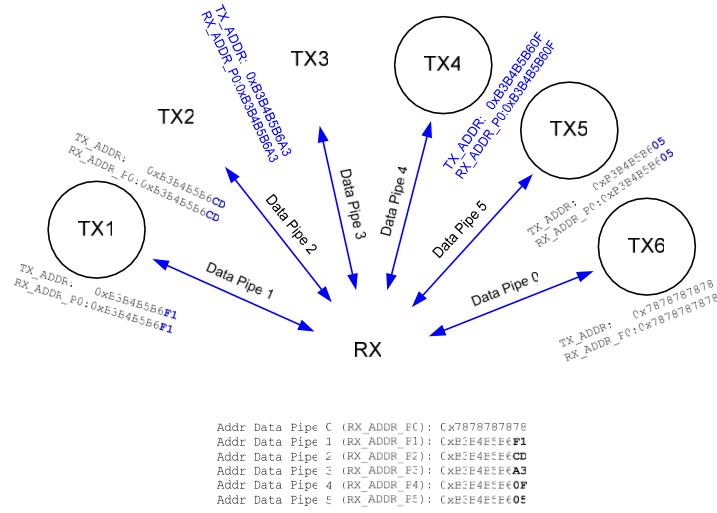


Figure 5: Example on how the acknowledgement addressing is done

An nRF24L01 configured as PTX with Enhanced ShockBurst™ enabled, will use the ShockBurst™ feature to send a packet whenever the microcontroller wants to. After the packet has been transmitted, nRF24L01 will switch on its receiver and expect an acknowledgement to arrive from the terminating part. If this acknowledgement fails to arrive, nRF24L01 will retransmit the same packet until it receives an acknowledgement or the number of retries exceeds the number of allowed retries given in the SETUP_RETRY_ARC register. If the number of retries exceeds the number of allowed retries, this will show in the STATUS register bit MAX_RT and gives an interrupt.

Whenever an acknowledgement is received by an nRF24L01 it will consider the last transmitted packet as delivered. It will then be cleared from the TX FIFO, and the TX_DS IRQ source will be set high.

With Enhanced ShockBurst™ nRF24L01 offers the following benefits:

- Highly reduced current consumption due to short time on air and sharp timing when operating with acknowledgement traffic
- Lower system cost. Since the nRF24L01 handles all the high-speed link layer operations, like re-transmission of lost packet and generating acknowledgement to received packets, it is no need for hardware SPI on the system microcontroller to interface the nRF24L01. The interface can be done by using general purpose IO pins on a low cost microcontroller where the SPI is emulated in firmware. With the nRF24L01 this will be sufficient speed even when running a bi-directional link.
- Greatly reduced risk of “on-air” collisions due to short time on air
- Easier firmware development since the link layer is integrated on chip



Enhanced ShockBurst™ Transmitting Payload:

1. The configuration bit PRIM_RX has to be low.
2. When the application MCU has data to send, the address for receiving node (TX_ADDR) and payload data (TX_PLD) has to be clocked into nRF24L01 via the SPI interface. The width of TX-payload is counted from 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, data pipe 0 has to be configured to receive the acknowledge. The receive address for data pipe 0 (RX_ADDR_P0) has to be equal to the transmit address (TX_ADDR) in the PTX device. For the example in Figure 5 the following address settings have to be performed 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 10 μ s.
4. nRF24L01 ShockBurst™:
 - Radio is powered up
 - 16 MHz internal clock is started.
 - RF packet is completed (see the packet description)
 - Data is transmitted at high speed (1 Mbps or 2 Mbps configured by MCU).
5. If auto acknowledgement is activated (Auto retransmit counter not equal zero, ENAA_P0=1) the radio goes into RX mode immediately. If a valid packet has been 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 acknowledgement is not received in the specified time window, the payload is resent (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 will be active when MAX_RT or TX_DS is high. To turn off the IRQ pin, the interrupt source must be reset by writing to the status register (see Interrupt chapter). If no acknowledgement is received for a packet after the maximum number of retries, no further packets can be sent before the MAX_RX interrupt is cleared. The packet loss counter (PLOS_CNT) is incremented at each MAX_RT interrupt. I.e. ARC_CNT counts the number of retries that was required to get a single packet through. PLOS_CNT counts the number of packets that did not get through even after maximum number of retries.
6. The device goes into Standby-I mode if CE is low. Otherwise next payload in TX FIFO will be sent. If TX FIFO is empty and CE is still high, the device will enter Standby-II mode.
7. If the device is in Standby-II mode, it will go to Standby-I mode immediately if CE is set low.

Enhanced ShockBurst™ Receive Payload:

1. RX is selected by setting the PRIM_RX bit in the configuration register to high, and then setting CE high.



2. After $130\mu\text{s}$ nRF24L01 is monitoring the air for incoming communication.
3. When a valid packet has been 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 will be active when RX_DR is high. RX_P_NO in status register will indicate what data pipe the payload has been received in.
4. If auto acknowledgement is enabled, an acknowledgement is sent back.
5. MCU sets the CE pin low to enter Standby-I mode (low current mode).
6. MCU can clock out the payload data at a suitable rate via the SPI interface.
7. The device is now ready for entering TX or RX mode or power down mode.

Auto Acknowledgement (RX)

The auto acknowledgement function reduces the load of the external microcontroller, and may remove the need for dedicated SPI hardware in a mouse/keyboard or comparable systems, and hence reduce cost and average current consumption. Auto acknowledgement can be configured individually for each data pipe via the SPI interface.

If auto acknowledgement is enabled and a valid packet (correct data pipe address and CRC) is received, the device will enter TX mode and send an acknowledgement packet. After the device has sent the acknowledgement packet, normal operation resumes, and the mode is determined by the PRIM_RX register and CE pin.

Auto Re-Transmission (ART) (TX)

An auto retransmission function is available. It will be used at the TX side in an auto acknowledgement system. In the SETUP_RETR register it will be possible to state how many times the data in the data register will be resent if data is not acknowledged. After each sending, the device will enter RX mode and wait a specified time period for acknowledgement. When the acknowledgement packet is received, the device will return to normal transmit function. If there is no more unsent data in the TX FIFO and the CE pin is low, the device will go into Standby-I mode. If the acknowledgement is not received, the device will go back to TX mode and resend the data. This will continue until acknowledgement is received, or a time out occurs (i.e. the maximum number of sending is reached). The only way to reset this is to set the PWR_UP bit low or let the auto retransmission finish. A packet loss counter will be incremented each time a packet does not succeed to reach the destination before time out. (Time out is indicated by the MAX_RT interrupt.) The packet loss counter is reset when writing to the RF channel register.

Packet Identity (PID) and CRC used by Enhanced ShockBurst™

Each packet contains a two bit wide PID field to detect if the received packet is new or resent. The PID will prevent that the PRX device presents the same payload more than once to the microcontroller. This PID field is incremented at the TX side for each new packet received via the SPI interface. The PID and CRC field is used by the PRX device to determine whether a packet is resent or new. When several data is lost on the link, the PID fields may in some cases become equal to last received PID. If a packet has the same PID as the previous packet, nRF24L01 will compare the CRC sums from both packets. If they also are equal, the last received packet is considered as a copy of the previous and is discarded.



1: PRX device:

The PRX device compares the received PID with the last PID. If the PID fields are different, the packet is considered to be new. If the PID is equal to last received PID, the received packet might be the same as last time. The receiver must check if the CRC is equal to the previous CRC. If the CRC is equal to the previous one, the packet is probably the same, and will be discarded.

2: PTX device:

The transmitter increments the PID field each time it sends a new packet.

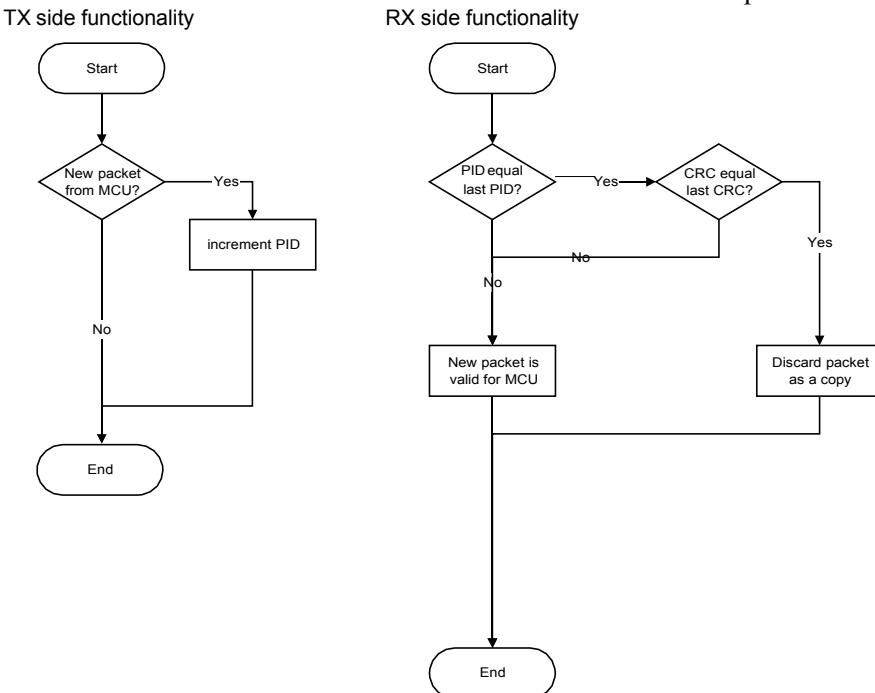


Figure 6 PID generation/detection

The length of the CRC is configurable through the SPI interface. It is important to notice that the CRC is calculated over the whole packet including address, PID and payload. No packet is accepted as correct if the CRC fails. This is an extra requirement for packet acceptance that is not illustrated in the figure above.

Stationary Disturbance Detection – CD

Carrier Detect (CD) is set high when an in-band RF signal is detected in RX mode, otherwise CD is low. The internal CD signal is filtered before presented to CD register. The internal CD signal must be high for at least 128 μ s.

In Enhanced ShockBurst™ it is recommended to use the Carrier Detect functionality only when the PTX device does not succeed to get packets through, as indicated by the MAX_RT interrupt for single packets and by the packet loss counter (PLOS_CNT) if several packets are lost. If the PLOS_CNT in the PTX device indicates too high rate of packet losses, the device can be configured to a PRX device for a short time ($T_{stbt2a} + CD\text{-filter delay} = 130\mu\text{s} + 128\mu\text{s} = 258\mu\text{s}$) to check CD. If CD was high (jam situation), the frequency channel should be changed. If CD was low



(out of range), it may continue on the same frequency channel, but perform other adjustments. (A dummy write to the RF_CH will clear the PLOS_CNT.)

Data Pipes

nRF24L01 configured as PRX can receive data addressed to 6 different data pipes in one physical frequency channel. Each data pipe has its own unique address and can be configured to have individual behavior.

The data pipes are enabled with the bits in the EN_RXADDR register. By default only data pipe 0 and 1 are enabled.

The address for each data pipe is configured in the RX_ADDR_Px registers. Always ensure that none of the data pipes have the exact same address.

Data pipe 0 has a unique 40 bit configurable address. Data pipes 1-5 share the 32 most significant address bits and have only the LSByte unique for each data pipe. Figure 7 shows an example of how data pipes 0-5 are addressed. All pipes can have up to 40 bit address, but for pipe 1-5 only the LSByte is different.

	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 7: Addressing data pipes 0-5

When a packet has been received at one of the data pipes and the data pipe is setup to generate acknowledgement, nRF24L01 will generate an acknowledgement with an address that equals the data pipe address where the packet was received.

Some configuration settings are common to all data pipes and some are individual. The following settings are common to all data pipes:

- CRC enabled/disabled (CRC always enabled when ESB is enabled)
- CRC encoding scheme
- RX address width
- Frequency channel
- RF data rate
- LNA gain
- RF output power



DEVICE CONFIGURATION

All configuration of nRF24L01 is defined by values in some configuration registers. All these registers are writable via the SPI interface.

SPI Interface

The SPI interface is a standard SPI interface with a maximum data rate of 10Mbps. Most registers are readable.

SPI Instruction Set

The available commands to be used on the SPI interface are shown below. Whenever CSN is set low the interface expects an instruction. Every new instruction must be started by a high to low transition on CSN.

In parallel to the SPI instruction word applied on the MOSI pin, the STATUS register is shifted serially out on the MISO pin.

The serial shifting SPI commands is on the format:

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

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

See Figure 8 and Figure 9.

Instruction Name	Instruction Format [binary]	# Data Bytes	Operation
R_REGISTER	000A AAAA	1 to 5 LSByte first	Read registers. AAAAA = 5 bit Memory Map Address
W_REGISTER	001A AAAA	1 to 5 LSByte first	Write registers. AAAAA = 5 bit Memory Map Address <i>Executable in power down or standby modes only.</i>
R_RX_PAYLOAD	0110 0001	1 to 32 LSByte first	Read RX-payload: 1 – 32 bytes. A read operation will always start at byte 0. Payload will be deleted from FIFO after it is read. Used in RX mode.
W_TX_PAYLOAD	1010 0000	1 to 32 LSByte first	Used in TX mode. Write TX-payload: 1 – 32 bytes. A write operation will always start at byte 0.
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, i.e. acknowledge package will not be completed.
REUSE_TX_PL	1110 0011	0	Used for a PTX device Reuse last sent payload. Packets will be repeatedly resent as long as CE is high. 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
NOP	1111 1111	0	No Operation. Might be used to read the STATUS register

Table 8 Instruction set for the nRF24L01 SPI interface.

The W_REGISTER and R_REGISTER may operate on single or multi-byte registers. When accessing multi-byte registers one will read or write MSBit of LSByte first. The



writing can be terminated before all bytes in a multi-byte register has been written. In this case the unwritten MSByte(s) will remain unchanged. E.g. the LSByte of RX_ADDR_P0 can be modified by writing only one byte to the RX_ADDR_P0 register. The content of the status register will always be read to MISO after a high to low transition on CSN.

Interrupt

The nRF24L01 has an active low interrupt pin (IRQ). The interrupt pin is activated when TX_DS, RX_DR or MAX_RT is set high in status register. When MCU writes '1' to the interrupt source, the IRQ pin will go inactive. The interrupt mask part of the CONFIG register is used to mask out the interrupt sources that are allowed to set the IRQ pin low. By setting one of the MASK bits high, the corresponding interrupt source will be disabled. By default all interrupt sources are enabled.

SPI Timing

The interface supports SPI. SPI operation and timing is given in Figure 8 to Figure 10 and in Table 9 and Table 10. The device must be in one of the standby modes or power down mode before writing to the configuration registers. In Figure 8 to Figure 10 the following notations are used:

Cn – SPI Instruction Bit

Sn – Status Register Bit

Dn – Data Bit (note: LSByte to MSByte, MSBit in each byte first)

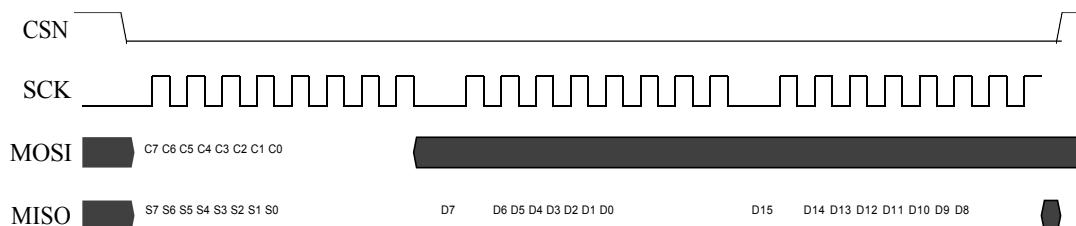


Figure 8 SPI read operation.

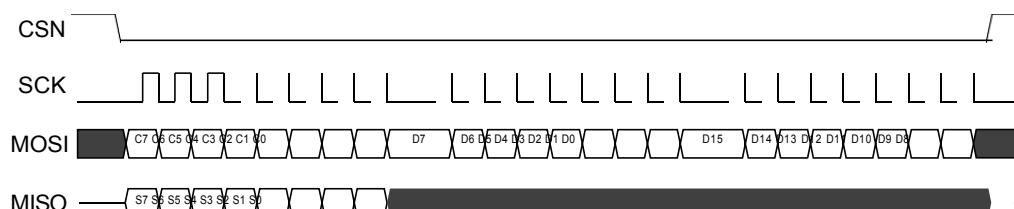


Figure 9 SPI write operation.

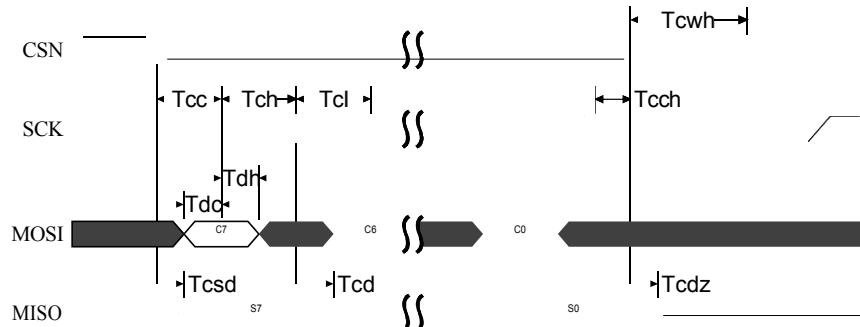


Figure 10 SPI NOP timing diagram.

PARAMETER	SYMBOL	MIN	MAX	UNITS
Data to SCK Setup	Tdc	2		ns
SCK to Data Hold	Tdh	2		ns
CSN to Data Valid	Tcsd		33	ns
SCK to Data Valid	Tcd		52	ns
SCK Low Time	Tcl	40		ns
SCK High Time	Tch	40		ns
SCK Frequency	Fsck	0	10	MHz
SCK Rise and Fall	Tr,Tf		tbd	ns
CSN to SCK Setup	Tcc	2		ns
SCK to CSN Hold	Tcch	2		ns
CSN Inactive time	Tcwh	50		ns
CSN to Output High Z	Tcdz		33	ns

Table 9 SPI timing parameters ($C_{load} = 5\text{pF}$).

PARAMETER	SYMBOL	MIN	MAX	UNITS
Data to SCK Setup	Tdc	2		ns
SCK to Data Hold	Tdh	2		ns
CSN to Data Valid	Tcsd		38	ns
SCK to Data Valid	Tcd		54	ns
SCK Low Time	Tcl	40		ns
SCK High Time	Tch	40		ns
SCK Frequency	Fsck	0	10	MHz
SCK Rise and Fall	Tr,Tf		tbd	ns
CSN to SCK Setup	Tcc	2		ns
SCK to CSN Hold	Tcch	2		ns
CSN Inactive time	Tcwh	50		ns
CSN to Output High Z	Tcdz		38	ns

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



Memory Map

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

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_RD 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
	CRC0	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	1: PRX, 0: PTX
01	EN_AA Enhanced ShockBurst™				Enable 'Auto Acknowledgment' Function Disable this functionality to be compatible with nRF2401, see page 25
	Reserved	7:6	00	R/W	Only '00' allowed
	ENAA_P5	5	1	R/W	Enable auto ack. data pipe 5
	ENAA_P4	4	1	R/W	Enable auto ack. data pipe 4
	ENAA_P3	3	1	R/W	Enable auto ack. data pipe 3
	ENAA_P2	2	1	R/W	Enable auto ack. data pipe 2
	ENAA_P1	1	1	R/W	Enable auto ack. data pipe 1
	ENAA_P0	0	1	R/W	Enable auto ack. 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.
	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 will be used if address width below 5 bytes
04	SETUP_RTR				Setup of Automatic Retransmission
	ARD	7:4	0000	R/W	Auto Re-transmit Delay

**nRF24L01 Single Chip 2.4 GHz Radio Transceiver**

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
					<p>‘0000’ – Wait 250+86uS ‘0001’ – Wait 500+86uS ‘0010’ – Wait 750+86uS ‘1111’ – Wait 4000+86uS (Delay defined from end of transmission to start of next transmission)</p>
	ARC	3:0	0011	R/W	<p>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</p>
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
	Reserved	7:5	000	R/W	Only '000' allowed
	PLL_LOCK	4	0	R/W	Force PLL lock signal
	RF_DR	3	1	R/W	<p>Data Rate ‘0’ – 1 Mbps ‘1’ – 2 Mbps</p>
	RF_PWR	2:1	11	R/W	<p>Set RF output power in TX mode '00' – -18 dBm '01' – -12 dBm '10' – -6 dBm '11' – 0 dBm</p>
	LNA_HCURR	0	1	R/W	Setup LNA gain
07	STATUS				Status Register (In parallel to the SPI instruction 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. Set high when new data arrives RX FIFO ¹³ . Write 1 to clear bit.
	TX_DS	5	0	R/W	Data Sent TX FIFO interrupt. Set high when packet sent on TX. If AUTO_ACK is activated, this bit will be set high only when ACK is received. Write 1 to clear bit.
	MAX_RT	4	0	R/W	Maximum number of TX retries interrupt Write 1 to clear bit. If MAX_RT is set it must be cleared to enable further communication.
	RX_P_NO	3:1	111	R	<p>Data pipe number for the payload available for reading from RX_FIFO 000-101: Data Pipe Number 110: Not Used 111: RX FIFO Empty</p>
	TX_FULL	0	0	R	TX FIFO full flag. 1: TX FIFO full. 0:

¹³ The Data Ready interrupt is set by a new packet arrival event. The procedure for handling this interrupt should be: 1) read payload via SPI, 2) clear RX_DR interrupt, 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 1).

**nRF24L01 Single Chip 2.4 GHz Radio Transceiver**

Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
Available locations in TX FIFO.					
08	OBSERVE_TX				Transmit observe register
	PLOS_CNT	7:4	0	R	Packet Loss Counter. The register is reset by writing to RF_CH. The counter restarts after 15 lost packets. See page 14 and 16.
	ARC_CNT	3:0	0	R	Current value on resent counter. The counter is reset when transmission of a new packet starts. See page 14.
09	CD				
	Reserved	7:1	000000	R	
	CD	0	0	R	Carrier Detect. See page 16.
0A	RX_ADDR_P0	39:0	0xE7E7E7E7E7	R/W	Receive address data pipe 0. 5 Bytes maximum length. (LSByte is written first)
0B	RX_ADDR_P1	39:0	0xC2C2C2C2C2	R/W	Receive address data pipe 1. 5 Bytes maximum length. (LSByte is written first)
0C	RX_ADDR_P2	7:0	0xC3	R/W	Receive address data pipe 2. Only LSB. MSBytes will be equal to RX_ADDR_P1[39:8]
0D	RX_ADDR_P3	7:0	0xC4	R/W	Receive address data pipe 3. Only LSB. MSBytes will be equal to RX_ADDR_P1[39:8]
0E	RX_ADDR_P4	7:0	0xC5	R/W	Receive address data pipe 4. Only LSB. MSBytes will be equal to RX_ADDR_P1[39:8]
0F	RX_ADDR_P5	7:0	0xC6	R/W	Receive address data pipe 5. Only LSB. MSBytes will be equal to RX_ADDR_P1[39:8]
10	TX_ADDR	39:0	0xE7E7E7E7E7	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 14.
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 Not Legal 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 Not Legal 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).

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Address (Hex)	Mnemonic	Bit	Reset Value	Type	Description
					0 Not Legal 1 = 1 byte ... 32 = 32 bytes
14	RX_PW_P3				
	Reserved	7:6	00	R/W	Only '00' allowed
	RX_PW_P3	5:0	0	R/W	Number of bytes in RX payload in data pipe 3 (1 to 32 bytes). 0 Not Legal 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 Not Legal 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 Not Legal 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	Reuse last sent data packet if set high. The packet will be repeatedly resent as long as CE is high. TX_REUSE is set by the SPI instruction REUSE_TX_PL, and is reset by the SPI instructions W_TX_PAYLOAD or FLUSH TX
	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 full flag. 1: RX FIFO empty. 0: Data in RX FIFO.
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 3 levels. Used in TX mode only
N/A	RX_PLD	255:0	X	R	Written by separate SPI command RX data payload register. 1 - 32 bytes. This register is implemented as a FIFO with 3 levels. All receive channels share the same FIFO

Table 11 Memory map of nRF24L01



Configuration for compatibility with nRF24XX

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

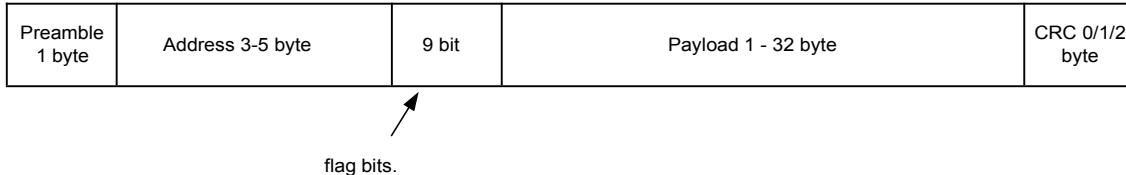
- Use same CRC configuration as the nRF2401/nRF2402/nRF24E1/nRF24E2 uses
- Set the PRIM_RX bit to 1
- Disable auto acknowledgement on the data pipe that will be addressed
- Use the same address width as the PTX device
- Use the same frequency channel as the PTX device
- Select data rate 1Mbit/s on both nRF24L01 and nRF2401/nRF2402/nRF24E1/nRF24E2
- Set correct payload width on the data pipe that will be addressed
- Set PWR_UP and CE high

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

- Use same CRC configuration as the nRF2401/nRF2402/nRF24E1/nRF24E2 uses
- Set the PRIM_RX bit to 0
- Set the Auto Retransmit Count to 0 to disable the auto retransmit functionality
- Use the same address width as the nRF2401/nRF2402/nRF24E1/nRF24E2 uses
- Use the same frequency channel as the nRF2401/nRF2402/nRF24E1/nRF24E2 uses
- Select data rate 1Mbit/s on both nRF24L01 and nRF2401/nRF2402/nRF24E1/nRF24E2
- Set PWR_UP high
- Clock in a payload that has the same length as the nRF2401/nRF2402/nRF24E1/nRF24E2 is configured to receive
- Pulse CE to send the packet

**PACKET DESCRIPTION**

An Enhanced ShockBurst™ packet with payload (1-32 bytes).



A ShockBurst™ packet compatible to nRF2401/nRF2402/nRF24E1/nRF24E2 devices.

Preamble 1 byte	Address 3-5 byte	Payload 1 - 32 byte	CRC 0/1/2 byte
--------------------	------------------	---------------------	-------------------

Preamble	<ul style="list-style-type: none"> Preamble is used to detect 0 and 1 levels. It is stripped off (RX) and added (TX) by nRF24L01. The preamble is 8 bits long.
Address	<ul style="list-style-type: none"> The address field contains the receiver address. The address can be 3, 4 or 5 bytes wide The address fields can be individually configured for all RX channels and the TX channel Address is automatically removed from received packets.¹⁴
Flags	<ul style="list-style-type: none"> PID: Packet Identification. 2 bits that is incremented for each new payload 7 bits reserved for packet compatibility with future products Not used when compatible to nRF2401/nRF24E1
Payload	<ul style="list-style-type: none"> 1 - 32 bytes wide.
CRC	<ul style="list-style-type: none"> The CRC is optional. 0-2 bytes wide CRC The polynomial for 8 bits CRC check is $X^8 + X^2 + X + 1$ The polynomial for 16 bits CRC check is $X^{16} + X^{12} + X^5 + 1$.

Table 12 Data packet description

¹⁴ Suggested use of addresses. In general more bits in the address gives less false detection, which in the end may give lower data Packet-Error-Rate (PER).

- The address made by (5, 4, or 3) equal bytes are not recommended because it in general will make the packet-error-rate increase.
- Addresses where the level shift only one time (i.e. 000FFFFFF) could often be detected in noise that may give a false detection, which again may give raised packet-error-rate.
- Addresses as a continuation of the preamble (hi-low toggling) will raise the Packet-Error-Rate (PER).



IMPORTANT TIMING DATA

The following timing applies for operation of nRF24L01.

nRF24L01 Timing Information

nRF24L01 timing	Max.	Min.	Name
Power Down \rightarrow Standby mode	1.5ms		Tpd2stby
Standby modes \rightarrow TX/RX mode	130 μ s		Tstby2a
Minimum CE high		10 μ s	Thce
Delay from CE pos. edge to CSN low		4 μ s	Tpece2csn

Table 13 Operational timing of nRF24L01

When the nRF24L01 is in power down it must always settle in Standby for 1.5ms before it can enter one of the TX or RX modes. Note that the configuration word will be lost if VDD is turned off and that the device then must be configured before going to one of the TX or RX mode.

Enhanced ShockBurst™ timing

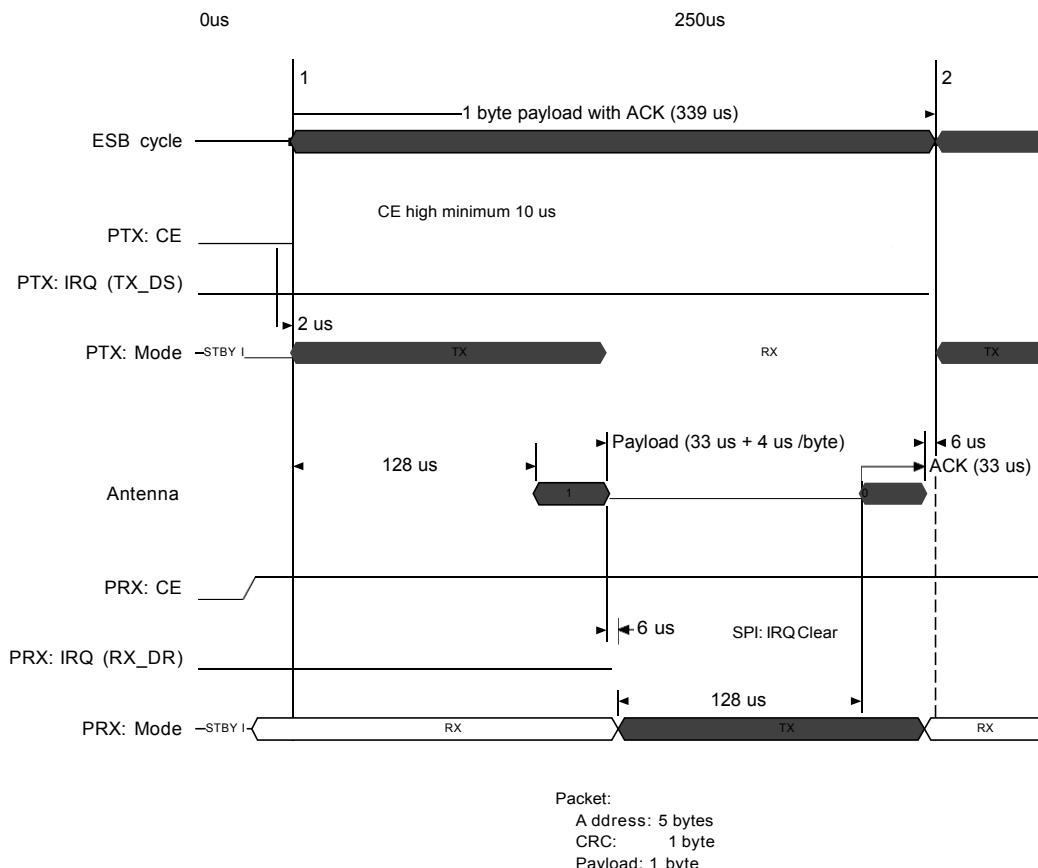


Figure 11 Timing of Enhanced ShockBurst™ for one packet upload (2Mbps).

nRF24L01 Single Chip 2.4 GHz Radio Transceiver

In Figure 11 the sending of one packet and the acknowledgement of this packet is shown. The loading of payload to the PTX device is not shown in the figure. The PRX device is turned into RX mode (CE=1), and the PTX device is set into TX mode (CE=1 for minimum 10 μ s). After 130 μ s the transmission starts and is finished after another 37 μ s (1 byte payload). The transmission ends, and the PTX device is automatically turned around to RX mode to wait for the acknowledgement from the PRX device. After the PTX device has received the acknowledgement it gives an interrupt to the MCU (IRQ (TX_DS) => TX-data sent). After the PRX device has received the packet it gives an interrupt to the MCU (IRQ (RX_DR) => RX-data ready).



PERIPHERAL RF INFORMATION

Antenna output

The ANT1 & ANT2 output pins provide a balanced RF output to the antenna. The pins must have a DC path to VDD, either via a RF choke or via the center point in a dipole antenna. A load of $100\Omega + j175\Omega$ is recommended for maximum output power (0dBm). Lower load impedance (for instance $50\ \Omega$) can be obtained by fitting a simple matching network.

Output Power adjustment

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

Conditions: VDD = 3.0V, VSS = 0V, $T_A = 27^\circ\text{C}$, Load impedance = $100\Omega + j175\Omega$.

Table 14 RF output power setting for the nRF24L01.

Crystal Specification

Frequency accuracy includes initial accuracy (tolerance) and stability over temperature and aging.

Frequency	C_L	ESR max	$C_{0\max}$	Frequency accuracy
16MHz	12pF	$100\ \Omega$	7.0pF	$\pm 60\text{ppm}$

Table 15 Crystal specification of the nRF24L01

To achieve a crystal oscillator solution with low power consumption and fast start-up time, it is recommended to specify the crystal with a low value of crystal load capacitance. Specifying $C_L=12\text{pF}$ is OK, but it is possible to use up to 16pF . Specifying a lower value of crystal parallel equivalent capacitance, C_0 will also work, but this can increase the price of the crystal itself. Typically $C_0=1.5\text{pF}$ at a crystal specified for $C_{0\max}=7.0\text{pF}$.

nRF24L01 sharing crystal with a micro controller.

When using a micro controller to drive the crystal reference input XC1 of the nRF24L01 transceiver some rules must be followed.

Crystal parameters:

When the micro controller drives the nRF24L01 clock input, the requirement of load capacitance C_L is set by the micro controller only. The frequency accuracy of $\pm 60\text{ ppm}$ is still required to get a functional radio link. The nRF24L01 will load the crystal by 0.5pF at XC1 in addition to the PBC routing.



Input crystal amplitude & Current consumption

The input signal should not have amplitudes exceeding any rail voltage, but any DC-voltage within this is OK. Exceeding rail voltage will excite the ESD structure and the radio performance is degraded below specification. If testing the nRF24L01 with a RF source with no DC offset as the reference source, the input signal will go below the ground level, which is not acceptable.

Figure 12 Principle of crystal oscillator

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



PCB layout and de-coupling guidelines

A well-designed PCB is necessary to achieve good RF performance. Keep in mind that a poor layout may lead to loss of performance, or even functionality, if due care is not taken. A fully qualified RF-layout for the nRF24L01 and its surrounding components, including matching networks, can be downloaded from www.nordicsemi.no.

A PCB with a minimum of two layers including a ground plane is recommended for optimum performance. The nRF24L01 DC supply voltage should be de-coupled as close as possible to the VDD pins with high performance RF capacitors, see Table 16. It is preferable to mount a large surface mount capacitor (e.g. 4.7 μ F tantalum) in parallel with the smaller value capacitors. The nRF24L01 supply voltage should be filtered and routed separately from the supply voltages of any digital circuitry.

Long power supply lines on the PCB should be avoided. All device grounds, VDD connections and VDD bypass capacitors must be connected as close as possible to the nRF24L01 IC. For a PCB with a topside RF ground plane, the VSS pins should be connected directly to the ground plane. For a PCB with a bottom ground plane, the best technique is to have via holes as close as possible to the VSS pads. At least one via hole should be used for each VSS pin.

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

**APPLICATION EXAMPLE**

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

Part	Designator	Footprint	Description
22pF ¹⁵	C1	0402	NPO, +/- 2%, 50V
22pF ¹⁵	C2	0402	NPO, +/- 2%, 50V
2.2nF	C3	0402	X7R, +/- 10%, 50V
4.7pF	C4	0402	NPO, +/- 0.25 pF, 50V
1.5pF	C5	0402	NPO, +/- 0.1 pF, 50V
1.5pF	C6	0402	NPO, +/- 0.1 pF, 50V
33nF	C7	0402	X7R, +/- 10%, 50V
1nF	C8	0402	X7R, +/- 10%, 50V
10nF	C9	0402	X7R, +/- 10%, 50V
6.8nH	L1	0402	chip inductor +/- 5%
3.3nH	L2	0402	chip inductor +/- 5%
3.9nH	L3	0402	chip inductor +/- 5%
1M	R1	0402	+/-10%
22K	R2	0402	+/- 1 %
nRF24L01	U1	QFN20 4x4	
16MHz	X1		+/-60ppm, Cl=12pF ¹⁵

Table 16 Recommended components (BOM) in nRF24L01 with antenna matching network

¹⁵C1 and C2 must have values that match the crystals load capacitance, Cl.



DEFINITIONS

Data sheet status	
Objective product specification	This data sheet contains target specifications for product development.
Preliminary product specification	This data sheet contains preliminary data; supplementary data may be published from Nordic Semiconductor ASA later.
Product specification	This data sheet contains final product specifications. Nordic Semiconductor ASA reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.
Limiting values	
Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Specifications sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

Table 17. Definitions

Nordic Semiconductor ASA reserves the right to make changes without further notice to the product to improve reliability, function or design. Nordic Semiconductor ASA does not assume any liability arising out of the application or use of any product or circuits described herein.

LIFE SUPPORT APPLICATIONS

These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Nordic Semiconductor ASA customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Nordic Semiconductor ASA for any damages resulting from such improper use or sale.

Preliminary Product Specification: Revision Date: 11.11.2005.

Data sheet order code: 111105-nRF24L01

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PRELIMINARY PRODUCT SPECIFICATION



nRF24L01 Single Chip 2.4 GHz Radio Transceiver

YOUR NOTES

PRELIMINARY PRODUCT SPECIFICATION



nRF24L01 Single Chip 2.4 GHz Radio Transceiver

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FCC Warning Statement

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment. This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- - Reorient or relocate the receiving antenna.
- - Increase the separation between the equipment and receiver.
- - Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- - Consult the dealer or an experienced radio/TV technician for help.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

OEM Statement

- a. The module manufacturer must show how compliance can be demonstrated only for specific host or hosts
- b. The module manufacturer must limit the applicable operating conditions in which the transmitter will be used, and
- c. The module manufacturer must disclose that only the module grantee can make the evaluation that the module is compliant in the host. When the module grantee either refuses to make this evaluation, or does not think it is necessary, the module certification is rendered invalid for use in the host, and the host manufacturer has no choice other than to use a different module, or take responsibility (§ 2.929) and obtain a new FCC ID for the product.
- d. The module manufacturer must provide the host manufacturer with the following requirements:
 - i. The host manufacturer is responsible for additional testing to verify compliance as a composite system. When testing the host device for compliance with Part 15 Subpart B, the host manufacturer is required to show compliance with Part 15 Subpart B while the transmitter module(s) are installed and operating. The modules should be transmitting and the evaluation should confirm that the module's intentional emissions are compliant (i.e. fundamental and out of band emissions).

2.2 List of applicable FCC rules

List the FCC rules that are applicable to the modular transmitter. These are the rules that specifically establish the bands of operation, the power, spurious emissions, and operating fundamental frequencies.

DO NOT list compliance to unintentional-radiator rules (Part 15 Subpart B) since that is not a condition of a module grant that is extended to a host manufacturer. See also Section 2.10 below concerning the need to notify host manufacturers that further testing is required.³

Explanation: This module meets the requirements of Part 15 Subpart C Section 15.249

2.3 Summarize the specific operational use conditions Describe use conditions that are applicable to the modular transmitter, including for example any limits on antennas, etc. For example, if point-to-point antennas are used that require reduction in power or compensation for cable loss, then this information must be in the instructions. If the use condition limitations extend to professional users, then instructions must state that this information also extends to the host manufacturer's instruction manual. In addition, certain information may also be needed, such as peak gain per frequency band and minimum gain, specifically for master devices in 5 GHz DFS bands.

Explanation: The EUT uses PCB Antenna, antenna gain: 0dBi. There is no restriction on the installation method.

2.4 Limited module procedures If a modular transmitter is approved as a "limited module," then the module manufacturer is responsible for approving the host environment that the limited module is used with. The manufacturer of a limited module must describe, both in the filing and in the installation instructions, the alternative means that the limited module manufacturer uses to verify that the host meets the necessary requirements to satisfy the module limiting conditions.

A limited module manufacturer has the flexibility to define its alternative method to address the conditions that limit the initial approval, such as: shielding, minimum signaling amplitude, buffered modulation/data inputs, or power supply regulation. The alternative method could include that the limited module manufacturer reviews detailed test data or host designs prior to giving the host manufacturer approval.

This limited module procedure is also applicable for RF exposure evaluation when it is necessary to demonstrate compliance in a specific host. The module manufacturer must state how control of the product into which the modular transmitter will be installed will be maintained such that full compliance of the product is always ensured. For additional hosts other than the specific host originally granted with a limited module, a Class II permissive change is required on the module grant to register the additional host as a specific host also approved with the module.

Explanation: The module is a limited module

2.5 Trace antenna designs

For a modular transmitter with trace antenna designs, see the guidance in Question 11 of KDB Publication 996369 D02 FAQ – Modules for Micro-Strip Antennas and traces. The integration information shall include for the TCB review the integration instructions for the following aspects: layout of trace design, parts list (BOM), antenna, connectors, and isolation requirements.⁴

- a) Information that includes permitted variances (e.g., trace boundary limits, thickness, length, width, shape(s), dielectric constant, and impedance as applicable for each type of antenna);
- b) Each design shall be considered a different type (e.g., antenna length in multiple(s) of frequency, the wavelength, and antenna shape (traces in phase) can affect antenna gain and must be considered);
- c) The parameters shall be provided in a manner permitting host manufacturers to design the printed circuit (PC) board layout;
- d) Appropriate parts by manufacturer and specifications;
- e) Test procedures for design verification; and
- f) Production test procedures for ensuring compliance.

The module grantee shall provide a notice that any deviation(s) from the defined parameters of the antenna trace, as described by the instructions, require that the host product manufacturer must notify the module grantee that they wish to change the antenna trace design. In this case, a Class II permissive change application is required to be filed by the grantee, or the host manufacturer can take responsibility through the change in FCC ID (new application) procedure followed by a Class II permissive change application.

Explanation: Yes. This module does not use Trace antenna designs.

2.6 RF exposure considerations

It is essential for module grantees to clearly and explicitly state the RF exposure conditions that permit a host product manufacturer to use the module. Two types of instructions are required for RF exposure information: (1) to the host product manufacturer, to define the application conditions (mobile, portable – xx cm from a person’s body); and (2) additional text needed for the host product manufacturer to provide to end users in their end-product manuals. If RF exposure statements and use conditions are not provided, then the host product manufacturer is required to take responsibility of the module through a change in FCC ID (new application).

Explanation: This module complies with FCC RF radiation exposure limits set forth for an uncontrolled environment.

2.7 Antennas

A list of antennas included in the application for certification must be provided in the instructions. For modular transmitters approved as limited modules, all applicable professional installer instructions must be included as part of the information to the host product manufacturer. The antenna list shall also identify the antenna types (monopole, PIFA, dipole, etc. (note that for example an “omni-directional antenna” is not considered to be a specific “antenna type”)).

For situations where the host product manufacturer is responsible for an external connector, for example with an RF pin and antenna trace design, the integration instructions shall inform the installer that unique antenna connector must be used on the Part 15 authorized transmitters used in the host product. The module manufacturers shall provide a list of acceptable unique connectors.

Explanation: The EUT uses PCB Antenna, antenna gain: 0dBi.

2.8 Label and compliance information

Grantees are responsible for the continued compliance of their modules to the FCC rules. This includes advising host product manufacturers that they need to provide a physical or e-label stating “Contains FCCID” with their finished product. See Guidelines for Labeling and User Information for RF Devices – KDB Publication 784748.

Explanation: The host system using this module, should have label in a visible area indicated the following texts: "Contains FCC ID: 2A63C-NRF24L01

2.9 Information on test modes and additional testing requirements

Additional guidance for testing host products is given in KDB Publication 996369 D04 Module Integration Guide. Test modes should take into consideration different operational conditions for a standalone modular transmitter in a host, as well as for multiple simultaneously transmitting modules or other transmitters in a host product.

The grantee should provide information on how to configure test modes for host product evaluation for different operational conditions for a stand-alone modular transmitter in a host, versus with multiple, simultaneously transmitting modules or other transmitters in a host.

Grantees can increase the utility of their modular transmitters by providing special means, modes, or instructions that simulates or characterizes a connection by enabling a transmitter. This can greatly simplify a host manufacturer’s determination that a module as installed in a host complies with FCC requirements.

Explanation: Data transfer module demo board can control the EUT work in RF test mode at specified test channel

2.10 Additional testing, Part 15 Subpart B disclaimer

The grantee should include a statement that the modular transmitter is only FCC authorized for the specific rule parts (i.e., FCC transmitter rules) listed on the grant, and that the host product manufacturer is responsible for compliance to any other FCC rules that apply to the host not covered by the modular transmitter grant of certification. If the grantee markets their product as being Part 15 Subpart B compliant (when it also contains unintentional-radiator digital circuitry), then the grantee shall provide a notice stating that the final host product still requires Part 15 Subpart B compliance testing with the modular transmitter installed.

Explanation: The module without unintentional-radiator digital circuitry, so the module does not require an evaluation by FCC Part 15 Subpart B. The host should be evaluated by the FCC Subpart B