nRF Performance Test Instructions

nRF24L01+

Application Note

November 2008

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1 Introduction

RF front end performance plays a vital role in the performance of any RF product, it is also the main area of testing when qualifying your nRF application for regulatory standards for RF emissions (like FCC, ETSI and TELEC). The test instructions presented in this document are the device setup, recommended instrument setup and necessary MCU routines required to perform the corresponding tests described in the nRF Performance Test Guidelines white paper available on our website.

The following nRF devices are covered by the instructions in this document:

- nRF24L01+: standalone 2.4GHz ISM band RF transceiver.
- nRF24LU1+: USB flash microcontroller with nRF24L01+ embedded.
- nRF24LE1

Note: The tests described in this document are intended for performance testing in the development stages of a product. Some of these tests can also be used during production testing while others are too complex and take too much time to be feasible for use in a production line.

2 Output power

The following setup enables you to run the output power tests described in chapter two of the RF Prototype Test Guidelines white paper.

2.1 TX carrier wave output

2.1.1 Device Configuration and data input

The configuration registers listed in Table 1. must be updated from their reset values to the test values to perform the output power test on the Device Under Test (DUT).

Register address	Mnemonic	Reset value (Hex)	Test value (Hex)	Comments
00	CONFIG	0x08	0x02	Bit 1: POWER_UP = 1
05	RF_CH	0x02	XX	RF_CH must be set depending on which frequency (F0) you want the carrier on. Formula: F0 = 2400 + RF_CH (MHz)
06	RF_SETUP	0x0F	0x9F	Bit 7: Cont wave = 1 Bit 4: PLL_lock = 1 If other than max. output power is wanted, bit2:1 must be set according to wanted output power, please refer to device product specification.

Table 1. Configuration registers required to be updated for TX carrier wave output

Note: Please refer to the Product Specifications for details on accessing the configuration registers.

2.1.2 Test routine

To run the test, the system MCU (external or embedded) must implement the following routine:

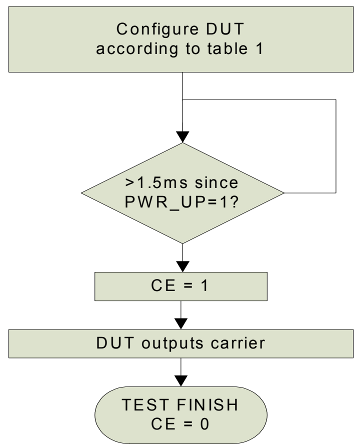

Figure 1. TX carrier wave output test routine

2.1.3 Test instrument setup

Optimal setup of the spectrum analyzer may vary from instrument to instrument, but the following recommendations are a good indication of a typical setup:

Parameter	Value	Comment
Centre frequency	F_0	Must be set to the same value as configured in the device RF_CH register following formula: F0 = 2400 + RF_CH (MHz).
Span	10 MHz	
Amplitude	5 dBm	
Resolution Band Width (RBW)	Auto	Can usually be set to auto to follow the span used. With a span of 10MHz this should give an RBW of 30-100 kHz.

Table 2. TX carrier wave test spectrum analyzer setup

2.2 TX carrier wave sweep

This section describes how you extend the TX carrier wave test described in section 2.1 on page 5 to a TX carrier wave sweep covering the 2.4GHz band.

2.2.1 Device configuration

Device configuration in this test is identical to the TX carrier wave (section 2.1 on page 5) except for register 05, which should be set to its minimum as stated in Table 3.

Register address	Mnemonic	Reset value (Hex)	Test value (Hex)	Comments
05	RF_CH	0x02	0x00	First channel is the lowest possible F0 (2400 MHz)

Table 3. Configuration registers required to be updated for TX carrier wave sweep

2.2.2 Test routine

This test builds on the TX carrier wave test routine:

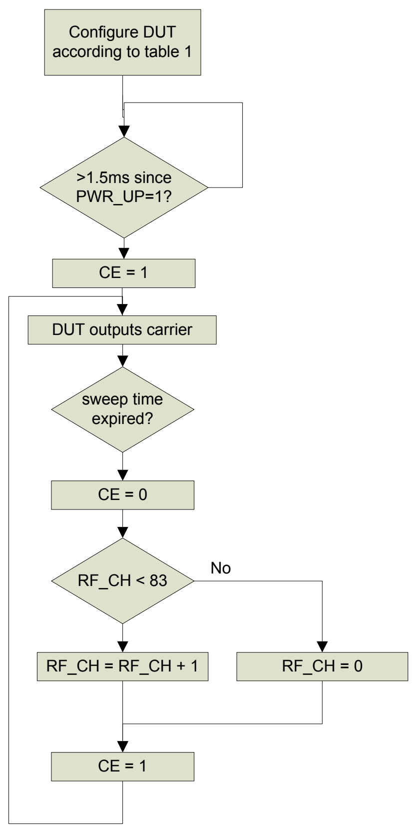

Figure 2. TX carrier wave sweep test routine

2.2.3 Test instrument setup

Optimal setup of the spectrum analyzer may vary from instrument to instrument, but the following recommendations are a good indication of a typical setup:

Parameter	Value	Comment
Centre frequency	2.42GHz	
Span	100 MHz	
Amplitude	5 dBm	
Resolution Band Width (RBW)	Auto	Can usually be set to auto to follow the span used. With a Span of 100MHz this should give a RBW of ~300kHz -1 MHz
Capture mode	Peak hold	Setting usually found in spectrum analyzer TRACE or AVERAGE menus

Table 4. TX carrier wave sweep test spectrum analyzer setup

3 Frequency accuracy

The following setup enables you to run the frequency accuracy test described in chapter four of the RF Prototype Test Guidelines white paper. Use the configurations and the MCU routine described in section 2.1 on page 5 of this document.

3.1 Test instrument setup

Optimal setup of the spectrum analyzer may vary from instrument to instrument, but the following recommendations are a good indication of a typical setup:

Parameter	Value	Comment
Centre frequency	F_0	Must be set to the same value as configured in the device RF_CH register following formula: F0 = 2400 + RF_CH (MHz)
Span	5 MHz	
Amplitude	5 dBm	
Resolution Band Width (RBW)	10kHz	Must be set according to the accuracy you want to measure

Table 5. Frequency accuracy test spectrum analyzer setup

4 Spurious emissions

The following setup enables you to run the spurious emission tests described in chapter three of the nRF Performance Test Guidelines white paper.

4.1 Harmonic output power

This test can use the device configuration and MCU routine from section 2.1 or section 2.2. By using the setup from section 2.2 you get a test showing the power on all possible harmonic output frequencies.

4.1.1 Test instrument setup

Optimal setup of the spectrum analyzer may vary from instrument to instrument, but the following recommendations are a good indication of a typical setup:

Parameter	Value	Comment
Centre frequency	N*2.42GHz	N=2, 3, 4 etc. depending on which harmonic you want to measure (2nd = 4.84GHz, 3rd = 7.26GHz etc.)
Span	2^{N-1} * 100 MHz	N=2, 3, 4 depending on which harmonic to be measured (2. = 200MHz, 3rd = 400 MHz)
Amplitude	5 dBm	
Resolution Band Width (RBW)	Auto	Can usually be set to auto to follow the span used. This should give an RBW of ~1-3MHz
Capture mode	Peak hold	Setting usually found in spectrum analyzer TRACE or AVERAGE menus

Table 6. Harmonic output power test spectrum analyzer setup

4.2 RX local oscillator leakage

Keep the MCU routine from section 2.2 but update the following configuration registers compared to what is listed in (Table 1.):

Register address	Mnemonic	Reset value (Hex)	Test value (Hex)	Comments
00	CONFIG	0x08	0x03	Bit 0: PRIM_RX = 1, enable receive Bit 1: POWER_UP = 1
05	RF_CH	0x02	0x00	First channel is the lowest possible F0 (2400 MHz)

Table 7. Updated configuration registers required for RX local oscillator leakage test

4.2.1 Test instrument setup

Optimal setup of the spectrum analyzer may vary from instrument to instrument, but the following recommendations are a good indication of a typical setup:

Parameter	Value	Comment
Centre frequency	2.77GHz	nRF24L01+ LO frequency for each RX channel is given by: F_{LO} = 8/7 (F_{RXCH} + 2 MHz) where F_{RXCH} is the frequency of your receive channel
Span	100 MHz	
Amplitude	-40 dBm	
Resolution Band Width (RBW)	Auto	This might need reduced in order to distinguish the LO leakage from the noise floor of the spectrum analyzer
Capture mode	Peak hold	Setting usually found in spectrum analyzer TRACE or AVERAGE menus

Table 8. RX local oscillator leakage test spectrum analyzer setup

5 Modulation Bandwidth

The following setup enables you to run the modulation bandwidth tests described in chapter five of the RF Performance Test Guidelines white paper.

5.1 Frequency deviation

To measure frequency deviation on the device you must send a sequence of identical packets creating a low frequency shift between the low and high FSK frequency.

5.1.1 Device Configuration and data input

The configuration registers listed in Table 9. must be updated from their reset values to the test values to perform the output power test.

Register address (Hex)	Mnemonic	Reset value (Hex)	Test value (Hex)	Comments
00	CONFIG	0x08	0x02	Bit 1: POWER_UP = 1 Bit 3: CRC_EN = 0
01	EN_AA	0x3F	0x00	Disable all auto acknowledge
04	SETUP_RETR	0x03	0x00	Disable all auto retransmit
05	RF_CH	0x02	xx	RF_CH must be set depending on which frequency (F0) the output is wanted on. Formula: F0 = 2400 + RF_CH (MHz)
06	RF_SETUP	0x0F	0x0F	Bit 5: Low air data rate 1 = 250kbps, 0 = bit 3 controls Bit 3: High air data rate 0 = 1Mbps, 1 = 2Mbps Given test value will set nRF24L01+ to 0dBm output @ 2 Mbps. If other than max. output power is wanted, bit2:1 must be set according to wanted output power, please refer to device product specification
10	TX_ADDR	0xE7E7E7E7E7	0xFF FF FF FF FF	

Table 9. Configuration registers required to be updated for frequency deviation

Data input (TX_FIFO content) in this test must be set to:

Number of bytes	Content
13 (0x00-0x0C)	0xFF
18 (0x0D-0x1F)	0x00

Table 10. Settings for data input in the frequency deviation test

5.1.2 Test routine

To run the test, the system MCU (external or embedded) must implement the following routine:

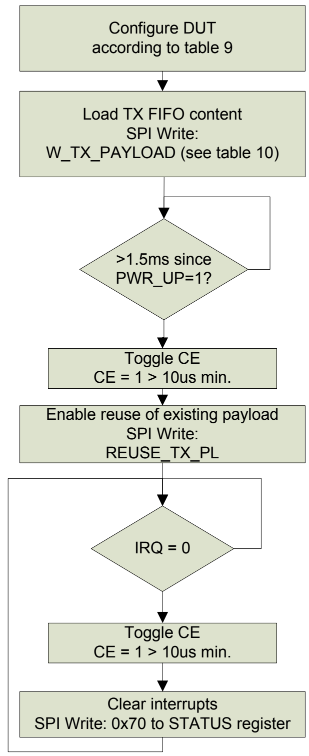

Figure 3. Frequency deviation test routine

By using the nRF interrupt features, the RF front end tells the MCU when it has finished sending the packet (default enabled after power on). The routine makes the radio send the same packet repeatedly as fast as possible. The benefit is that there is no need to change the MCU routine if the data rate is changed. If the RF front end interrupt features are not used the CE can toggle at a maximum rate of ~0.2 ms @ 2 Mbps, ~0.5 ms @ 1 Mbps and 1.5 ms @ 250 kbps.

5.1.3 Test instrument setup

Optimal setup of the spectrum analyzer may vary from instrument to instrument, but the following recommendations are a good indication of a typical setup:

Parameter	Value	Comment
Centre frequency	F_0	Must be set to same value as configured in the device RF_CH register following formula: F0 = 2400 + RF_CH (MHz)
Span	10 MHz	
Amplitude	5 dBm	
Resolution Band Width (RBW)	Auto	Can usually be set to auto to follow the span used. With a Span of 10MHz this should give an RBW of 30-100 kHz
Capture mode	Peak hold	Setting usually found in spectrum analyzer TRACE or AVERAGE menus

Table 11. TX deviation test spectrum analyzer setup

5.2 TX modulation bandwidth

Use the MCU test routine and instrument setup described in section 5.1. The device's TX address and payload content must be changed according to the following tables.

Register address (Hex)	Mnemonic	Reset value (Hex)	Test value (Hex)	Comments
10	TX_ADDR	0xE7E7E7E7E7	0x80 42 30 9C AB	5 byte PRBS data

Table 12. Configuration register required to be updated for TX modulation bandwidth

Data input (TX_FIFO content) in this test must be set to:

Number of bytes	Content (Hex)	Comment
32	(hex) 0xA6 E4 50 AD 3F 64 96 FC 9A 99 80 C6 51 A5 FD 16 3A CB 3C 7D D0 6B 6E C1 6B EA A0 52 BC BB 81 CE 93 D7 51 21 9C 2F 6C D0 EF 0F F8 3D F1 73 20 94 ED 1E 7C D8 A 9 1C 6D 5C 4C 44 02	32 bytes PRBS data

Table 13. Settings for data input in the TX modulation bandwidth test

6 Receiver sensitivity

The following set up enables you to run the receiver sensitivity test described in chapter six of the RF Performance Test Guidelines white paper. To run this test, the system MCU (external or embedded) must implement the general receiver sensitivity routine found in chapter six of the RF Performance Test Guidelines white paper.

6.1 Device Configuration

The configuration registers listed in Table 14. must be updated from their reset values to the test values to perform the output power test.

Register address (Hex)	Mnemonic	Reset value (Hex)	Test value (Hex)	Comments
00	CONFIG	0x08	0x03	Bit 3: CRC_EN = 0 Bit 1: POWER_UP = 1 Bit 0: PRIM_RX = 1
01	EN_AA	0x3F	0x00	Disable all auto acknowledge
04	SETUP_RETR	0x03	0x00	Disable all auto retransmit
05	RF_CH	0x02	XX	RF_CH must be set depending on which frequency (F0) the device is to receive on. Formula: F0 = 2400 + RF_CH (MHz)
06	RF_SETUP	0x0F	0x07	Bit 5: Low air data rate 1 = 250kbps, 0 = bit 3 controls Bit 3: High air data rate 0 = 1Mbps, 1 = 2Mbps Given test value will set nRF24L01+ to 2 Mbps
0A	RX_ADDR_P0	0xE7E7E7E7E7	0x80 42 30 9C AB	5 bytes random address pattern
11	RX_PW_P0	0	0x20	32 bytes payload length

Table 14. Configuration registers required to be updated for Receiver sensitivity

6.2 Test Instrument setup

This is the RF generator setup you need to generate a valid input signal:

Parameter	Value	Comment
RF Frequency	F_0	Must be set to the same value as configu-red in the device RF_CH register following formula: F0 = 2400 + RF_CH (MHz)
Modulation	2 GFSK	
Data rate	1 or 2 Mbps	Must match DUT RF_SETUP register
Deviation	±160 or ±320 kHz	Must match DUT: ±160 kHz @ 250kbps and 1 Mbps, ±320 kHz @ 2 Mbps
BT	0.5 Gaussian	
Recommended packet build	**Preamble:** (hex)AA **Address:** (hex) 0x08 C2 72 AC 37 **Payload:** (hex) 0xA6 E4 50 AD 3F 64 96 FC 9A 99 80 C6 51 A5 FD 16 3A CB 3C 7D D0 6B 6E C1 6B EA A0 52 BC BB 81 CE 93 D7 51 21 9C 2F 6C D0 EF 0F F8 3D F1 73 20 94 ED 1E 7C D8 A 9 1C 6D 5C 4C 44 02	38 byte sequence sent over and over again from the RF generator. MCU routine in DUT must compare received data to Payload defined here and count number of errors in each received payload

Table 15. Receiver sensitivity test instrument setup

7 Receiver selectivity

The following setup enables you to run the receiver selectivity test described in chapter seven of the RF Performance Test Guidelines white paper. To run this test, the system MCU (external or embedded) must implement the general receiver selectivity routine found in chapter seven of the RF Performance Test Guidelines white paper. Use all RF generator 1 device configuration and instrument setup from the receiver sensitivity test in chapter six of the RF Performance Test Guidelines white paper.

Note: The receiver selectivity in nRF devices is decided by the nRF device design. Therefore, this test only verifies the numbers already listed in nRF product specifications.

7.1 Test Instrument setup

The second RF generator in this test can send a carrier, using the following configuration:

Parameter	Value	Comment
RF Frequency	xx	Varied in steps to find co-, adjacent channel and wide band blocking, please refer to the RF Performance Test Guidelines white paper
Output power	xx	Varied in steps to find co-, adjacent channel and wide band blocking, please refer to the RF Performance Test Guidelines white paper
Modulation	OFF	

Table 16. Receiver selectivity test setup

Alternatively, the second RF generator can use the same configuration as the first generator to mimic an interfering second nRF24L01+ device or it can be set up to mimic other common radio systems like Bluetooth.

Note: In the case of mimicking a second nRF24L01+ device, the 'address' pattern sent from generator 1 and 2 MUST be different.