FCC/ETSI confirmity test guidelines for nRF24Z1

1. Preface

Upon completion of the application design, the product must be tested for compliance with the telecommunication regulations in force for the region in which the product is to be sold. This test must be conducted by an independent test laboratory certified to perform compliancy tests.

Prior to compliancy tests, the product/application designer should familiarize himself with the tests to be conducted by the test lab. Some tests require preparation of software and hardware in order to perform the required tests.

This whitepaper contains:

- Compliance test overview
- Description of hardware required for compliance testing
- Suggested compliancy test measurement setup
- Documentation background containing;
    - Test item description example
    - Functional description of the nRF24Z1 communication protocol
    - Description of the nRF24Z1 FHSS engine

Targeted readers are test laboratory engineers and application engineers.

Although ETSI and FCC certification involve somewhat different requirements, the measurements involved and their motivation are quite similar. The reader should refer to the relevant valid documents (www.etsi.org and www.fcc.gov) for updated regulations.

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2. Test and documentation overview

The tests involved are described in detail in the following documents:

FCC part 15.247
Frequency Hopping Transmitters / Digital Transmission System

RSS-210, Issue 6
Low Power License-Exempt Radiocommunication Devices

EN 300 328 V1.6.1 (2004-11)
European Harmonized Standard Candidate.
Electromagnetic compatibility and Radio spectrum Matters (ERM)

It is emphasized that the intention of the compliancy tests is to confirm that the application is within the specified limits in terms of intentional and unintentional radiated power *in normal use*. Any modifications to the application software/hardware should therefore be minimal, and should only be performed when this is absolute necessary for measurement purposes.

Chapters 2.1 thru 2.4 describe the main test sections and the documentation requirements of the compliancy tests.

2.1. Antenna radiation characteristics

The antenna radiation characteristics are measured by measuring the radiated power at a fixed frequency whilst rotating the antenna in the horizontal plane and changing the device elevation in the azimuth-plane from -90° to +90°. Alternatively, the EUT is rotated 360 and the reference antenna elevation is changed.

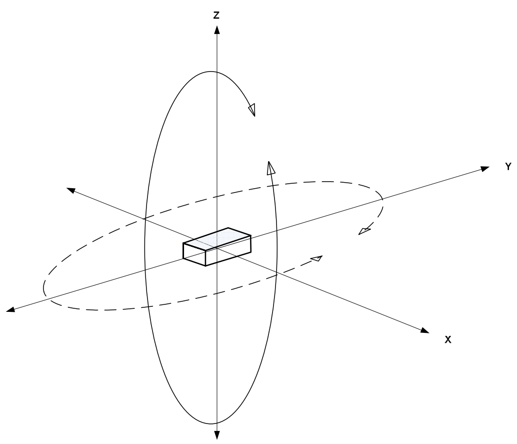


Figure 1 – Determining maximum EIRP

2.2. Output power measurement

The maximum power recorded in the previous measurement is defined as the output power of the device.

The radiated power is recorded for three frequencies (lowest-, middle- and highest operation frequencies). Orientation of the EUT is the one yielding the highest measured power in Chapter 2.1.

2.3. Spurious frequency component measurement

With the orientation yielding the highest power reading found in Chapter 2.1 the spurious emissions over a wide frequency band is monitored for TX-mode and RX-mode as different requirements apply for the two modes of operation.

2.4. Communication behavior and FHSS characterization

This information is divided into two sections; a measurement section and a system description section. The system description must be prepared by the application designer and should contain information concerning hopping table and hopping algorithm characteristics, antenna types etc.

2.4.1. Measurements

A series of measurements are conducted in order to verify compliance with behavioral characteristics for frequency hopping / spread spectrum systems. This includes:

- Frequency separation of hopping frequencies
- Number of hopping frequencies
- Duration of frequency occupancy (Dwell time)
- Modulation bandwidth (20dB)

2.4.2. Documentation

Documentation describing functionality and application specifics (text and illustration) must be provided. This includes:

- Antenna type and connection characteristics, also how it is ensured that EIRP limits are compliant with limits for the antennas designed for use with the device
- Technical description of how the application meets the definition of a FHSS system
- Description of how the hopping sequence is generated and how the available frequencies are used equally on average
- Description of how the ARX obtains frequency synchronization with the ATX

A draft of the documentation section is found in Appendix A-1.

3. Compliance test details

This section contains a description of the measurements involved in the compliancy test and information necessary to effectively locate and identify frequency spurs in an nRF24Z1 based application.

3.1. Test flowchart

Figure 2.a and 2.b shows the test flowchart with comments for the radiated and conducted power measurements.

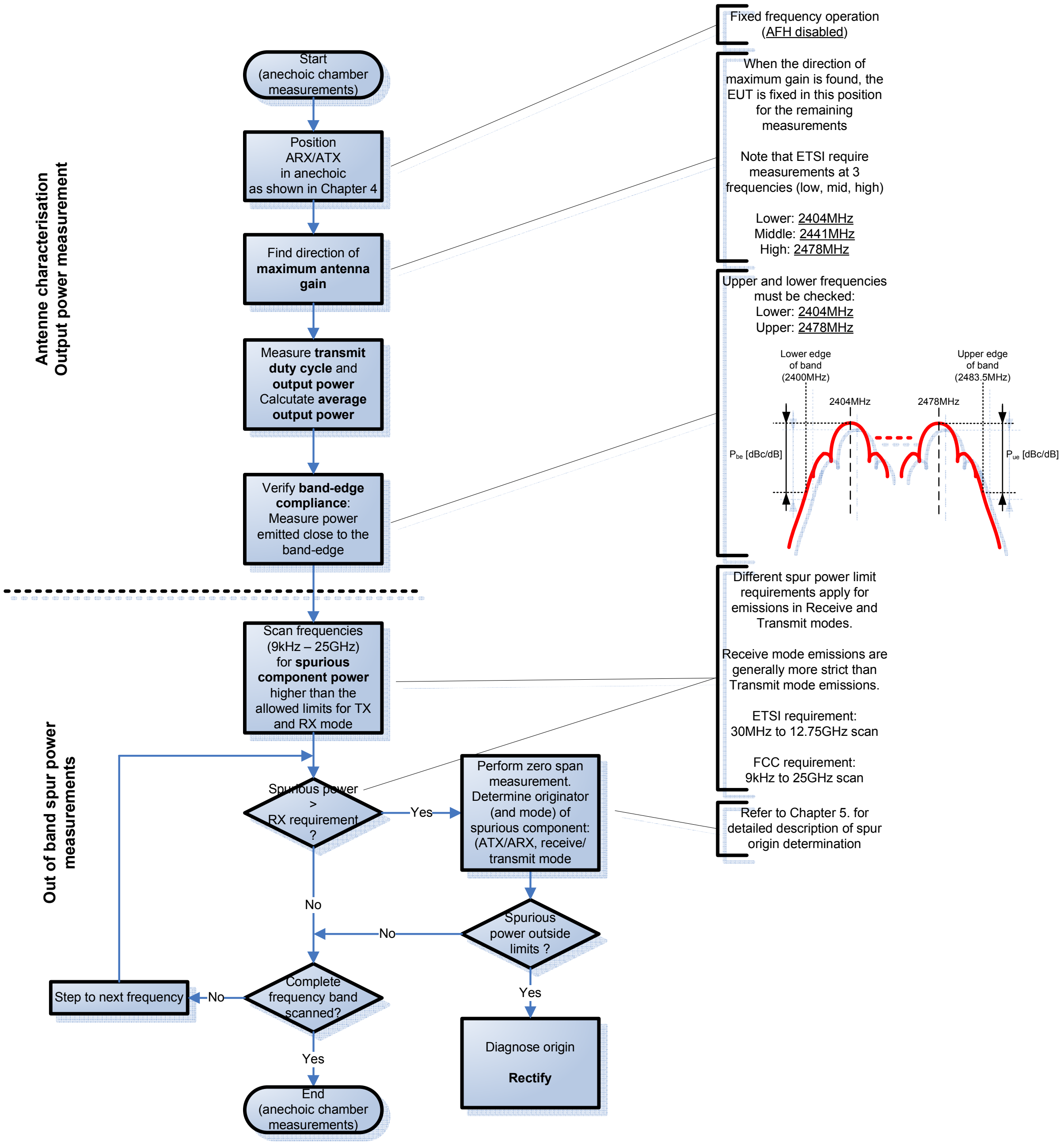


Figure 2.a – Compliancy test measurement flowchart (radiated)

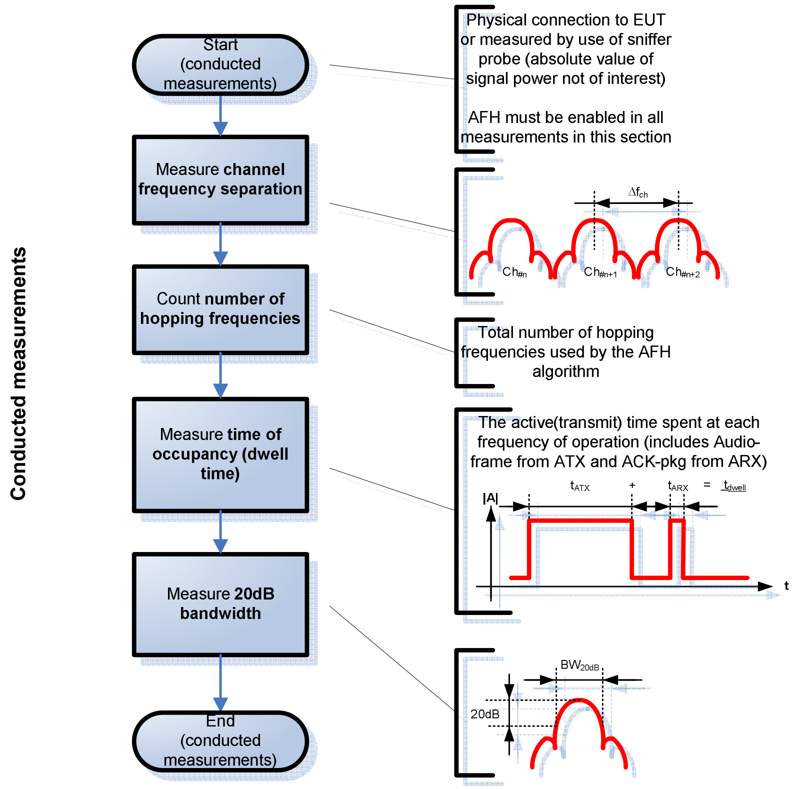


Figure 2.b – Compliancy test measurement flowchart (conducted)

The compliancy test flowchart differentiates between *conducted* and *radiated* power measurements.

Radiated power measurements are used when absolute power level readings are needed (e.g. spurious power level and band-edge power levels). This is done by measuring the received electromagnetic energy at a given distance from the EUT and then calculating the effective transmitted power.

Conducted power measurements are used when only relative power readings are needed (e.g. counting the number of hopping channels in use, measuring the 20dB bandwidth etc.). These are measurements that may be performed either by connecting a cable (in)directly to the antenna terminals of the EUT. This may also be done by ‘sniffing’ the output signal by attaching a makeshift antenna to the EUT. Conducted power measurements may be performed outside an anechoic chamber, typically reducing laboratory costs.

3.2. Spurious frequency component locations

While in transmit mode, the nRF24Z1 perform a direct modulation of the carrier frequency. The frequency components resulting thereof, are the modulated signal with odd- and even harmonics. These occur at

$$f_{TX\_N} = (2400 + CH_{\#no}) \cdot N \ \text{[MHz]} \tag{1}$$

Where $CH_{\#no}$ is the frequency position and N = 1,2,3,4…

While in receive mode, the nRF24Z1 frequency synthesizer generates the local oscillator frequency for the front end mixer.
The nRF24Z1 is a superheterodyne receiver of which the location of the LO-frequency spur can be found as;

$$f_{LO} = (TX_{frequency} + 6) \cdot \frac{8}{7} \ \text{[MHz]} \tag{2}$$

Example: the LO-frequency spur is located at (2400 + 6)·8/7 = 2749.71 MHz when the operating frequency (TX-frequency) is set to 2400MHz.

Figure 3 illustrates the spurious components normally identified in the test.

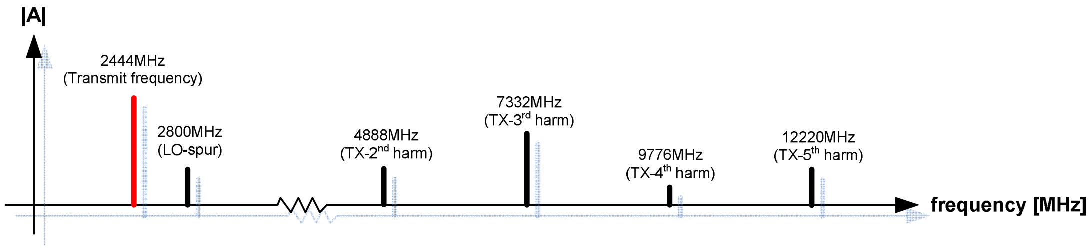


Figure 3 – Spur locations for the nRF24Z1 device

3.3. Interpretation of zero span measurement results

As measurements are performed with both application units active, a zero span measurement is used in order to distinguish which unit and mode of operation is generating the spur in question.

Figure 4 shows the operation modes of the application units ARX and ATX. As shown, the ATX is the unit transferring the largest amount of data while the ARX is receiving. At fixed intervals, the ARX transmits a short ACK-package while the ATX is receiving. In between these timeslots, both units are in standby mode (RF-circuitry in power down, whilst the embedded microcontroller is running). This repetitive cycle is easily identified in a zero span measurement as shown in Figure 5.

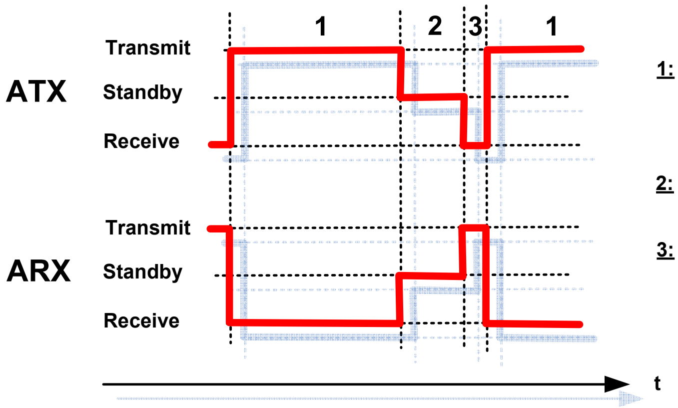


Figure 4 – Operation modes for the ATX and ARX during audio data transfer

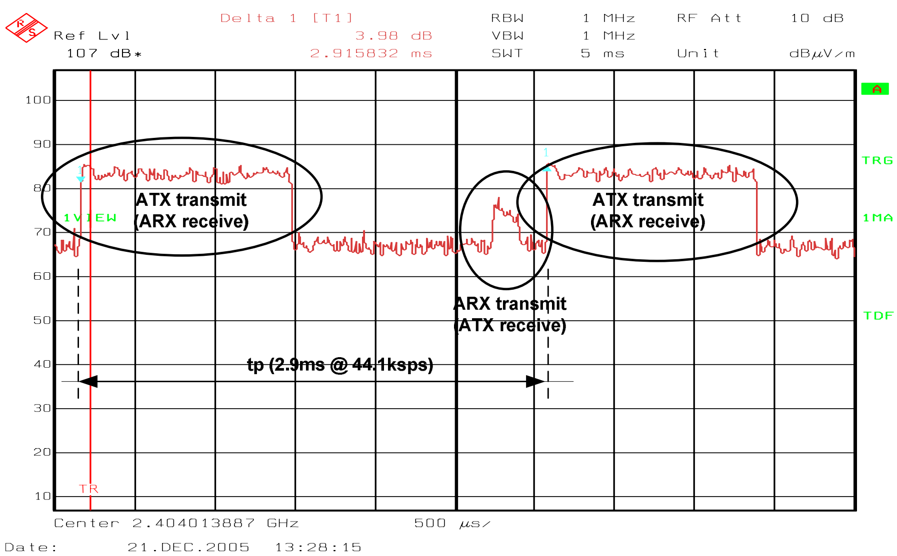


Figure 5 – Zero span measurement of the nRF24Z1 audio streamer demonstration kit (ATX measurement as shown in Figure 7)

3.4. Recommended spur measurement procedure

The recommended measurement procedure is listed below. Figure 6 illustrates the procedure graphically.

1. Position the ARX and ATX as described in Chapter 4.1.

2. Scan the frequency band for spurs with magnitude larger than the most stringent requirement (Maximum spurious emission while in receive mode).

3. When a frequency spur is found, a zero span plot measurement must be performed for the given frequency. The unit and mode of origin may be determined upon completion of stage 5 (Identical measurement, but with switched positions for the ATX/ARX).

    If the spur is a TX-related spur, power must be lower than the maximum allowed with the given duty-cycle compensation.

    If the spur is a RX-related spur, power must be lower than the maximum allowed with the given duty-cycle compensation

4. Position the ARX and ATX as described in Chapter 4.2.

5. Repeat stages 2. and 3.

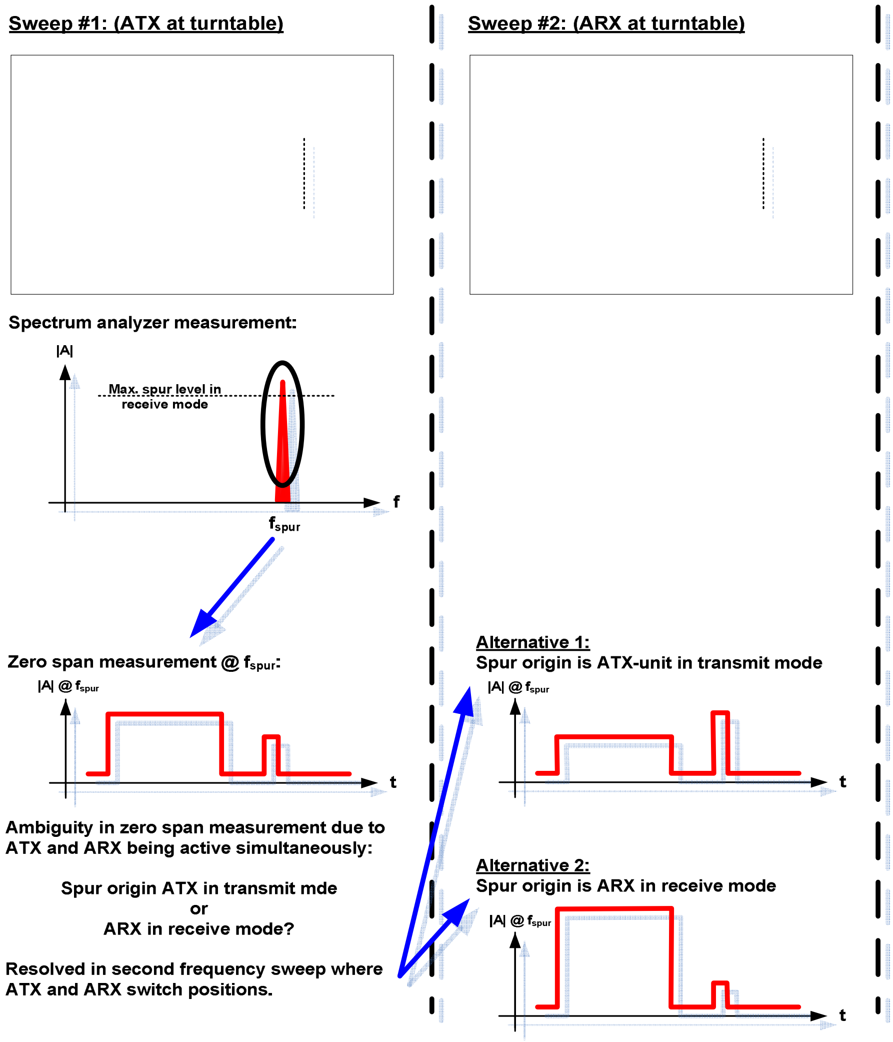


Figure 6 – Spur measurements; resolving unit and mode of origin

4. Compliance test setup recommendation

This chapter describes the recommended test setup for a nRF24Z1-based application.

4.1. Recommended ATX test setup

Figure 7 shows the recommended test setup.

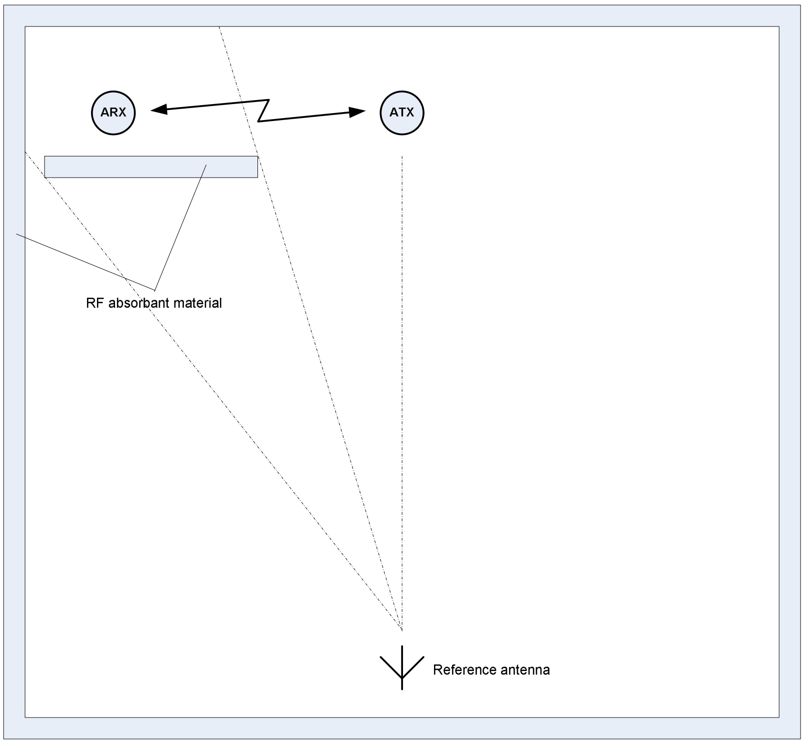


Figure 7 – Anechoic chamber measurement principle.

The ATX unit is positioned at the nonconductive turntable in the boresight of the reference antenna. The ARX is positioned so close to the ATX that audio streaming is possible for all orientations of the ATX-antenna. The ARX device may be positioned for maximum gain (if this is known) in the direction of the ATX.

In order to suppress ARX radiated power to the extent that it does not contribute to ATX measurements, an RF absorbing mat/wall should be positioned between the ARX and the reference antenna.

4.2. Recommended ARX test setup

The test setup is identical to that of the ATX test, but the ATX and ARX units switch location.

5. Required hardware

The test procedure requires hardware with some adjustments in order to cover all aspects of the conformity measurements. *This hardware should be prepared by the application vendor prior to the conformity tests.*

The required hardware is:

HW1: The final application with the designated software complete w. enclosures.
This implies the complete application with ATX-unit and ARX-unit. An audio source compatible with the application must be available.

HW2: As above, but with AFH-disabled. Communication at a fixed channel.
Measurements require *fixed channel measurements* at three frequencies (low, centre and high). This implies that the application must be able to be manually set to the three following frequencies:

Frequency #1: 2.404GHz (Channel setting #4)
Frequency #2: 2.441GHz (Channel setting #41)
Frequency #3: 2.478GHz (Channel setting #78)

Depending on HW realization, this may be implemented by EEPROM program alteration/switch settings at done at the testsite or w. three separate prepared HW-kits.

HW3: 'Sniffer' antenna with 50Ω SMA/BNC connector.
Some measurements involve equipment monitoring communication characteristics of the application (i.e. hopping rate, burst duration etc.). *This does not involve absolute value power measurements and may be performed outside an anechoic chamber*. The sniffer antenna may be an aftermarket antenna (i.e. the λ/2-wave monopole supplied with the nRF24Z1-EVALKIT) or a custom antenna (i.e. an open λ/2-wave dipole made from a coaxial cable with split end). The sniffer antenna must be positioned close to the units in order to obtain sufficient power level for the measurements.

6. Summary

The test procedure described in this document is custom tailored for the nRF24Z1 device and allows testing while in normal audio streaming mode. The proposed test guidelines have been used for FCC/ETSI compliancy tests by Nemko Comlab AS (www.comlab.no). The nRF24Z1 reference design was used as test object. Reference design information, test reports and compliancy confirmation may be obtained from the Nordic semiconductor website (www.nordicsemi.no).

The test objectives of the ETSI and FCC compliancy regulations are quite similar and do only differ at detail level.

The application designer should be familiar with the individual tests and the test objective of these. Especially prepared hardware and firmware is required in order to perform all the necessary tests. Preparation of hardware / firmware must be performed prior to tests and should be discussed with laboratory test personnel if diverging from the specifications listed in this document.

In addition to the hardware required for the test, documentation describing essential properties of the application must be prepared for the test laboratory. The appendix contains relevant documentation examples.

It should be noted that interpretation of regulations may differ somewhat for different test laboratories. Nordic semiconductor may assist the application vendor and test laboratory when expedient.

APPENDIX A-1 : Documentation background

The following sub-chapters may be used directly or with minor modifications as supplementary documentation background for the ETSI/FCC test report documents.

A.1.1 Description of Test Item

Example of text:

The nRF24Z1-HPR1-ATX together with the nRF24Z1-HPR1-ARX is a complete system for one-way wireless digital audio transfer from an audio source to an audio recipient. A 3.5mm jack on the nRF24Z1-HPR1-ATX unit connects to an audio source like e.g. a CD player or MP3 player. A 3.5mm jack on the nRF24Z1-HPR1-ARX unit is used for connection to headphones or speakers. The nRF24Z1-HPR1-ATX and the nRF24Z1-HPR1-ARX units are the radio parts of the nRD24-02, nRF24Z1 Headphone Reference Design 1 from Nordic Semiconductor ASA.

Similar text describing the characteristics of the application must be provided by the application designers

A.1.2 Theory of Operation

The system is based on one-way wireless digital audio transfer from an audio source to an audio recipient. The application consists of an ATX (audio source) and an ARX (audio receiver). Figure 1 shows the application hardware and communication principle.

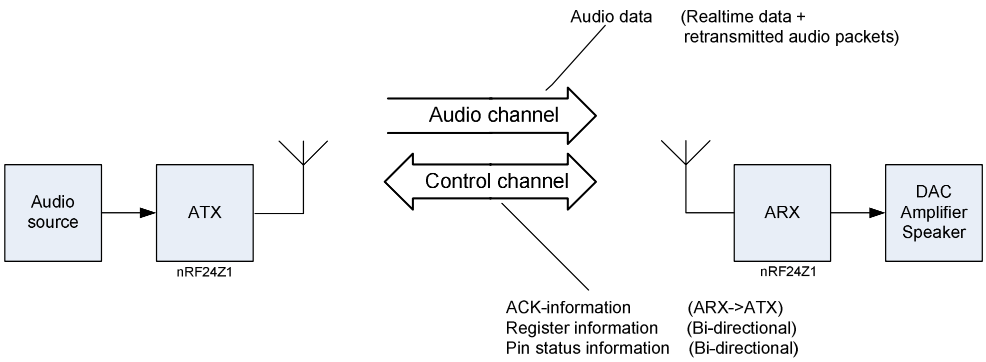


Figure A.1 - nRF24Z1 based audio streamer application

It is noted that communication between ATX and ARX are based on half-duplex transmission, where the following actions take place on a cyclic basis:

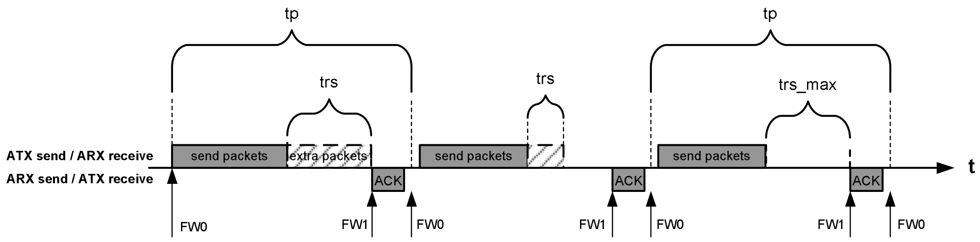
1. The ATX transmits audio and control data in a data frame to the ARX
(ATX-Transmit, ARX-Receive)
2. The ARX responds to the ATX with an ACK-packet
(ARX-Transmit, ATX-Receive)
3. ARX and ARX changes frequency according to AFH-algorithm
4. Step 1 thru 3 are repeated

If reception conditions are poor, the ARX requests retransmission of corrupt audio data packets (their sequence number and ID is relayed back to the ATX via the ACK-packet). These retransmitted packets are added to the nominal ATX dataframe illustrated in Figure A.2. The application is a FHSS system where only one dataframe is sent at a given frequency location before hopping to the next.

The cyclic period, t_p (hopping rate) is 2.91ms for the 44.1KHz sampling rate configuration setting (If using other configuration settings; refer to Figure A.2 or datasheet for values).

Please refer to Chapter 4 Architectural overview in the nRF24Z1 Product Specification for details.

FW0 = Flywheel interrupt 0
FW1 = Flywheel interrupt 1 (ATRX/ARX changes frequency @ FW1)
tp = Period duration
trs = Time interval used to retransmit packets
trs_max= Maximum time available for packet retransmission



tp	= f(fs)	tp (48kHz)	= 2.67 ms	Extra packet capacity (48kHz)	= 5
trs	= f(lost packets)	tp (44.1kHz)	= 2.9 ms	Extra packet capacity (44.1kHz)	= 6
trs_max	= f(fs)	tp (32kHz)	= 4.0 ms	Extra packet capacity (32kHz)	= 13

Figure A.2 - nRF24Z1 half duplex communication principle

A.1.3 Pseudo random properties of the embedded FHSS engine

The embedded FHSS engine uses 38 hopping locations, out of which 18 are non-overlapping channels. The hopping sequence is contained in a table with the 38 frequency location entries staggered in a pseudorandom order (See Figure A.3). A single data frame is transmitted on each frequency location before skipping to the next hopping frequency in the list. Upon completion of the list, the hopping sequence is repeated on a cyclic basis.

Upon reception of faulty/no data, the frequency(ies) resulting in loss of data, is temporarily removed from the hopping sequence. The hopping sequence cycle is thus correspondingly shortened. The frequency locations resulting in loss of data are added to a list of banned frequencies containing the frequency locations unsuitable for use. This list is limited to a maximum number (NBCH), set to 0x12 in this application.

The duration of the ban is given by the equation (BCHD+1) · NBCH · t_p
The BCHD parameter is set to 0x0A and t_p *is 2.91ms for the 44.1KHz sampling setting.*

In normal operation, the initial pseudorandom list of frequency hopping locations is volatile in terms of the number of hopping frequencies in use and the sequence of which they occur. These elements combined result in an unpredictable hopping sequence with pseudorandom properties. Hopping positions are used equally on average with even noise distribution in the band.

Table number 1

																CH28	46	CH33	26
CH0	06	CH4	18	CH8	2C	CH12	40	CH16	08	CH20	1E	CH24	32	CH29	12	CH34	3E		
CH1	1C	CH5	30	CH9	44	CH13	0C	CH17	20	CH21	36	CH25	4A	CH30	2A	CH35	0A		
CH2	34	CH6	48	CH10	10	CH14	24	CH18	38	CH22	4E	CH26	16	CH31	42	CH36	22		
CH3	4C	CH7	14	CH11	28	CH15	3C	CH19	04	CH23	1A	CH27	2E	CH32	0E	CH37	3A		

Figure A.3 - Frequency hopping table example
(Actual frequency can be calculated from formula: (2.400 + CHx) [GHz])

A.1.4 Frequency synchronization of ATX/ARX units

While streaming audio data the ARX continuously sends information about the 8 next frequency positions to be used (information contained in ACK-packet). In the event of ACK from the ARX being lost, the ATX will know the next 7 frequencies to use. After 8 hops without ACK the communication link is lost.

Upon loosing link, communication is re-established by the ARX entering receive-mode at a fixed channel for a given duration. The ATX transmits link-locate packets expected by the ARX. The link-locate packets are transmitted at each of the frequencies used in the hopping sequence. Upon reception of a link-locate packet, the ARX transmits an ACK-packet to the ATX, re-establishing the audio link.

APPENDIX A-2 : List of abbreviations

ACK	Acknowledgement
AFH	Adaptive Frequency Hopping
ATX	Audio Transmitter (nRF24Z1 functional mode)
ARX	Audio Receiver (nRF24Z1 functional mode)
BCHD	Banned Channel Hopping Duration
BNC	Bayonet Neill Concelman (connector)
DAC	Digital to Analog Converter
EUT	Equipment Undergoing Test
EEPROM	Electrically Erasable and Programmable Memory
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Committee
FHSS	Frequency Hopping Spread Spectrum
HW	HardWare
LO	Local Oscillator
NBCH	Number of Banned CHannels
RF	Radio Frequency
RX	Receiver
SMA	SubMiniature version A (connector)
TX	Transmitter

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