nRF9160 Hardware Verification Guidelines

nWP-034

White Paper

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Contents

Revision history

Date	Description
2021-05-07	Editorial changes

2021-03-30	Updated to match nRF9160 B1A
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	  • UICC interface on page 11
	  • RF conducted performance test – Signaling mode – GPS mode on page 14
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April 2020	First release

1 Introduction

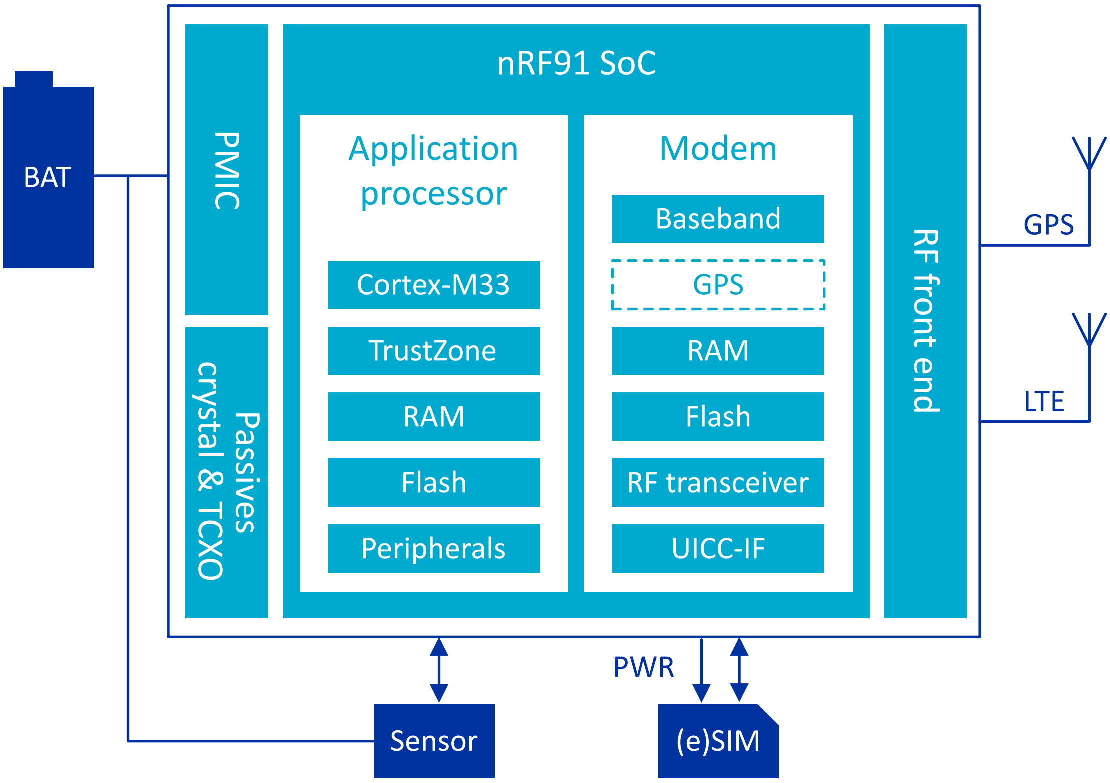
This document provides guidelines for the hardware verification testing of nRF9160. It is intended for Nordic Semiconductor's customers, especially system integrators and hardware engineers.

nRF9160 is an *LTE made simple* cellular IoT *System in Package (SiP)* that is pre-certified for building end products. nRF9160 consists of an Arm® Cortex®- M33 microcontroller and 3GPP LTE release 13 compliant embedded *LTE-M* and *Narrowband Internet of Things (NB-IoT)* LTE modem.

The microcontroller has a built-in 1 MB flash memory, Arm TrustZone® technology, and 32 general purpose I/O pins. The LTE modem has a transceiver with global cellular band coverage, ultra-low current consumption, and single 50 Ω antenna interface. In addition, the modem supports a *Global Positioning System (GPS)* receiver from a second 50 Ω antenna interface.

External to the nRF9160 *SiP* are supply source, *Subscriber Identity Module (SIM)* solution, antenna with matching circuitry, and any peripherals or sensors.

The following diagram shows an overview of the nRF9160 *SiP*.



For more information on the features and specifications of nRF9160, see nRF9160 Product Specification.

The features described in this document are supported by modem firmware v1.1.0 and later.

2 Product design setup for verification purposes

Hardware and firmware preparations are needed to communicate with nRF9160 in different test cases.

2.1 Test interfaces

nRF9160 uses *Serial Wire Debug (SWD)* and *Universal Asynchronous Receiver/Transmitter (UART)* interfaces for device controls. They should be accessible to support testing functionalities.

2.1.1 SWD interface

The *SWD* debug interface is used for programming the firmware and accessing registers. *SWD* can be accessed, for example, with SEGGER J-Link debugger hardware. A standard 2 x 5 pin header interface can be found on the nRF9160 *Development Kit (DK)*.

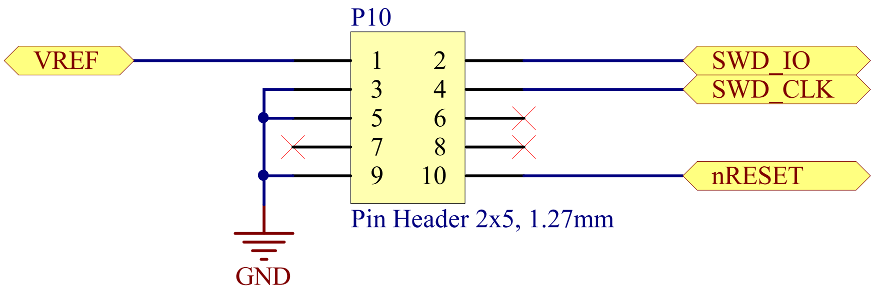


Figure 1: Example of SWD connections

2.1.2 UART interface

UART communicates through the GPIO pins. All GPIO pins can be configured for *UART* communication in the application firmware. The *UART* interface can be used to control the *Device Under Test (DUT)* using AT commands.

The *UART* interface is useful for logging transactions between the LTE network and the nRF9160 modem. The modem log is required for technical support if problems related to the LTE network occur.

If a *Universal Serial Bus (USB)* interface is required, a *USB-UART* bridge cable can be used, for example from FTDI. You can also add a *USB-UART* converter on a test board, as shown in Figure 2: Example of USB-UART converter based on FTDI circuit on page 7.

The nRF9160 and *USB-UART* converter must have the same I/O voltage level. Thus, VCCIO is equal to **`VDD_GPIO`** in the following figure.

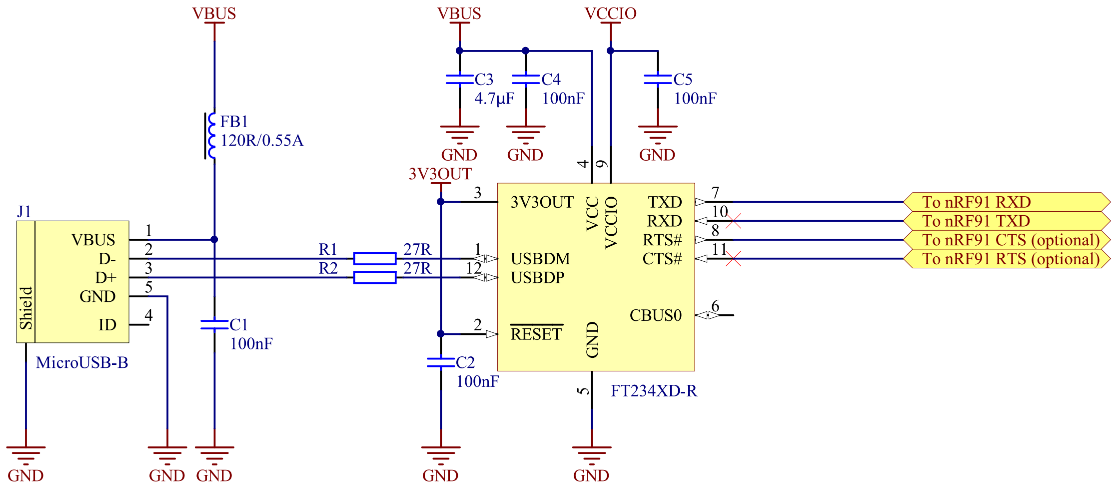


Figure 2: Example of USB-UART converter based on FTDI circuit

Note: The *USB-UART* converter can be placed on a separate adapter board for cost-efficient production.

2.2 Modem firmware

nRF9160 is preprogrammed with modem firmware. The preprogrammed firmware supports AT commands that are described in this document and needed for the most common test cases.

The **%SHORTSWVER** AT command can be used to check the version of the preprogrammed modem firmware. For more information, see Short software identification %SHORTSWVER in nRF91 AT Commands Reference Guide.

2.2.1 Hardware version B0A

nRF9160's hardware version B0A is preprogrammed with a complete modem firmware. It is recommended to update the modem firmware to a newer version before the product is sent to customers. The AT commands supported by the modem firmware are described in nRF91 AT Commands Reference Guide.

2.2.2 Hardware version B1A

nRF9160's hardware version B1A is preprogrammed with the *Production Test Image (PTI)* modem firmware. *PTI* supports a subset of AT commands for testing in non-signaling mode. The modem firmware needs to be updated for signaling mode testing and end customer use.

For more information, see Production test features in nRF91 AT Commands Reference Guide.

2.3 Setting up AT command interface

To control the nRF9160 LTE modem with AT commands, an application program that routes AT commands from the computer is needed. Nordic offers the AT Client application for this purpose. The AT Client firmware needs to be compiled according to the product hardware pin mapping.

nRF Connect SDK includes AT Client's source code. The compiled AT Client firmware is available for the nRF9160 *DK* at nRF9160 DK Downloads. For more information on AT Client, see nRF9160: AT Client.

Available AT commands can be found in nRF91 AT Commands Reference Guide.

3 R&D and QA verification

This section describes measurements on power consumption, *Universal Integrated Circuit Card (UICC)* interface, and RF to verify performance and quality of the product.

3.1 Checking supply voltages

The expected values of the voltage levels on the **VDD**, **VDD_GPIO**, and **DEC0** pins are shown in the following table.

Parameter	Min	Max	Description
VDD voltage	3.0 V	5.5 V	Main power supply input voltage
VDD_GPIO voltage	1.8 V	3.6 V	GPIO input voltage
DEC0 voltage	2.1 V	2.3 V	Module internal power supply

Table 1: Voltage levels of VDD, VDD_GPIO, and DEC0

Battery voltage at the **VDD** input of nRF9160 can be read with the Nordic-proprietary **%XVBAT** AT command that shows the **VDD** voltage level seen by nRF9160. The response to the command is the battery voltage in mV.

The following command example reads the battery voltage:

```
AT%XVBAT
%XVBAT: 3600 // measured battery voltage 3600mV
OK
```

3.2 Controlling GPIO pins with SWD

SWD debug interface can be used for controlling GPIO pins if the functionality needs to be verified without firmware control. This section shows examples of testing the functionality of the GPIO pins in the input and output modes.

> **Note:** If application firmware has already been programmed, firmware-configured peripherals may need to be disabled separately to ensure the correct functioning of the *SWD* control.

For more information on the GPIO pin control, see GPIO - General purpose input/output in nRF9160 Product Specification.

3.2.1 Example of GPIO test in input mode

In the following example, a GPIO test is done in the input mode with *SWD* controls.

1. Write the GPIO pins connected with drive strength H0H1:
   - Address: 0x50842700 (+ n x 0x4 for GPIO0-31)
   - Data: 0x300
2. Write the GPIO pins to the input mode:

- Address: 0x50842514
- Data: 0x0

3. Set the GPIO pins to the wanted state from a production tester.
4. Read the GPIO status.
   - Address: 0x50842510
5. Compare the read value to the tester setting.

For information on GPIO, see GPIO - General purpose input/output in nRF9160 Product Specification.

3.2.2 Example of GPIO test in output mode

In the following example, a GPIO test is done in the output mode with *SWD* controls.

1. Write the GPIO pins connected with drive strength H0H1:
   - Address: 0x50842700 (+ n x 0x4 for GPIO0-31)
   - Data: 0x300
2. Set the GPIO pins to the output mode:
   - Address: 0x50842514
   - Data: 0xFFFFFFFF
3. Write the GPIO pins to the wanted state.

   For example:
   - Set even pins low and odd pins high:
     - Address: 0x50842504
     - Data: 0xAAAAAAAA
   - Set odd pins low and even pins high:
     - Address: 0x50842504
     - Data 0x55555555
4. Measure the voltage in the GPIO pins, for example, with an oscilloscope.
   Use a suitable load current, for example, 1 mA to verify the quality of the contact.

For information on GPIO, see GPIO - General purpose input/output in nRF9160 Product Specification.

3.3 Power consumption

nRF9160 has two power inputs: **VDD** for internal parts and **VDD_GPIO** for GPIO pins. **VDD_GPIO** consumption should be observed in measurements, because load on any GPIO pin is visible on **VDD_GPIO**.

nRF9160 contains an internal *DC/DC* converter operating in a hysteretic mode when the device is in a low power consumption state. In this mode, the internal *DC/DC* periodically charges supply capacitors. The charging cycle creates spikes in current consumption. During a charging period, current consumption is typically in the mA range, but during a quiet period it can be less than 1 µA.

The performance of the test equipment should be carefully considered when setting up a power consumption measurement system. The most important criteria are good sensitivity for low currents, high dynamic range, and good sample rate. For example, Keysight 6715C power analyzer with auto-ranging power modules and Keithley DMM7510 multimeter are viable options. Nordic Semiconductor's Power Profiler Kit II can also be used for current consumption measurements.

Temperature has a significant impact on current consumption in the low power mode. The current consumption is higher in high temperatures and lower in cold temperatures. Accurate and repeatable measurements require stable temperature in the test environment.

The measured current depends on the battery voltage. The current consumption decreases with higher battery voltage. As a result, the consumed power in watts is approximately constant.

It is important to verify transient behavior in **VDD** voltage under maximum power RF transmission and ensure that the **VDD** level stays within expected values. Too low **VDD** during RF transmission may degrade signal quality and cause a *DUT* reset.

Figure 3: PSM, cDRX, and iDRX current consumption example on page 10 shows an example of nRF9160 waking up from the *Power Saving Mode (PSM)* mode, performing a *Tracking Area Update (TAU)* towards the LTE network, entering connected mode *Discontinuous Reception (DRX)* for three seconds, and finally entering idle mode *DRX*. The RF transmission is done with maximum power. The resulting peak current consumption is approximately 300 mA in this example measurement.

Power consumption between the idle mode *DRX* paging periods is in the µA range. In Figure 3: PSM, cDRX, and iDRX current consumption example on page 10, the zoomed-in image from that period shows typical *PSM* mode consumption with a *DC/DC* converter charging pulses.

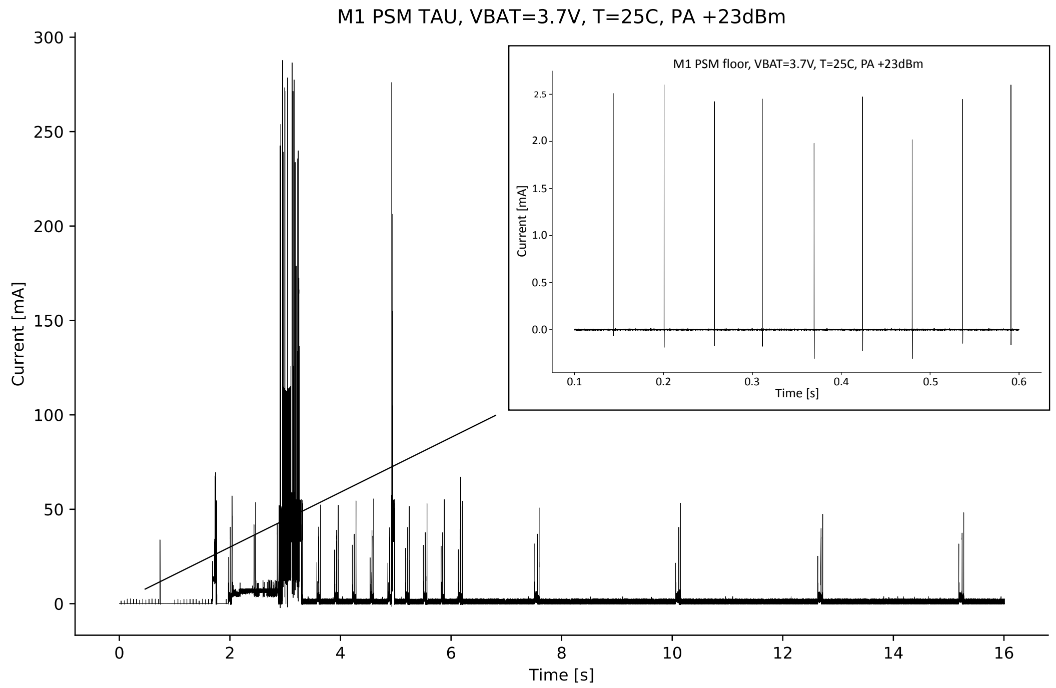


Figure 3: PSM, cDRX, and iDRX current consumption example

Note: Power consumption is heavily impacted by network conditions, and the settings and may vary significantly.

For typical current consumption in different operational states, see Current consumption in nRF9160 Product Specification.

For more information on measuring current consumption on the nRF9160 *DK*, see Measuring current in nRF9160 DK User Guide.

For estimating current consumption and battery life at an early stage of design, see the Online Power Profiler tool in Nordic Semiconductor DevZone.

3.4 UICC interface

nRF9160 supports only the *UICC* Class C interface with 1.8 V nominal voltage as described in *ETSI TS 102 221*. The electrical specifications for all *UICC* signals that should be verified in product design and prototyping phase are defined in *ETSI TS 102 221, chapter Electrical specifications of the UICC* . ETSI documents can be downloaded from https://www.etsi.org.

Test item	ETSI test ID	Temp/ Voltage	Expected result	Note
Supply voltage VSIM	5.3.1	TYP/TYP	1.75–1.85 V	ETSI specification minimum 1.62 V
Reset signal	5.3.2		V_{oh} > 1.5 V V_{ol} < 0,3 V t_R/t_F < 400 µs	Rise and fall time may be impacted by EMI/ESD protection
Clock signal	5.3.3		V_{oh} > 1.5 V V_{ol} < 0,3 V t_R/t_F < 50 ns	Rise and fall time may be impacted by EMI/ESD protection
I/O signal	5.3.4		V_{oh} > 1.5 V V_{ol} < 0,3 V t_R/t_F < 50 ns	Rise and fall time may be impacted by EMI/ESD protection

Table 2: UICC interface performance tests

Basic *UICC* verification can be done with an oscilloscope. If a more advanced test setup is needed, for example Comprion's IT³ Prove! can be used.

If a device has a user-accessible slot for a *UICC* card, ESD sensitivity should be verified against type approval limits. The nRF9160 internal ESD protection is intended for a 1.5 kV Human Body Model (HBM) level. An external ESD/EMI filter is recommended between the *UICC* card slot and the nRF9160 *SiP*. For an example case, see nRF9160 DK Hardware files. For more information, see UICC in nWP037 - nRF9160 Hardware Design Guidelines.

3.5 Testing RF performance

The RF performance of nRF9160 is designed to meet the *3GPP TS 36.101* specification. RF performance can be tested with a cellular tester that supports RF measurements specified in the 3GPP specification, such as Rohde & Schwartz CMW500 or Anritsu MT8821C.

Nordic Semiconductor has used CMW500 in internal RF performance verification. For details on the options needed on CMW500 for the *LTE-M* and *NB-IoT* modes, see Appendix on page 45.

Radiated performance should also be verified. This testing requires an anechoic RF chamber, and therefore it is usually done by a test house offering this kind of service.

The following figure shows an example setup for a signaling mode RF performance test. A separate RF signal generator can be used for *GPS* measurements or the signal can be taken from an LTE tester.

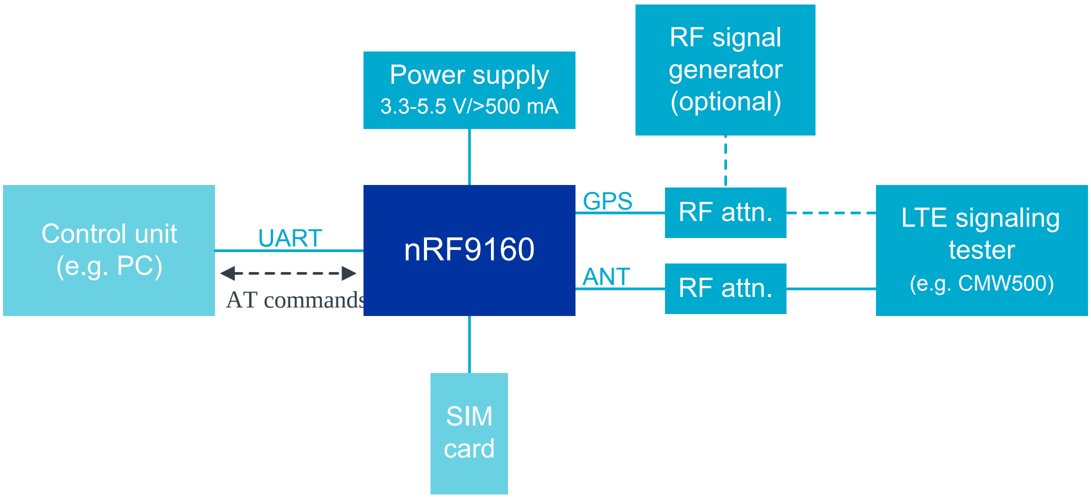


Figure 4: Signaling mode RF test setup

3.5.1 RF conducted performance test

RF conducted performance test is recommended to be performed in the R&D phase to verify the RF performance of the end product. A verified conducted test provides a solid background for entering radiated RF tests.

The *LTE-M* and *NB-IoT* tests described in Signaling mode on page 12 and Non-signaling mode on page 15 are based on specifications in *3GPP TS 36.101*.

The tests should be performed with a 50 Ω test connector or soldered cable.

3.5.1.1 Signaling mode

In the signaling mode, a connection is established towards the tester, and nRF9160 is controlled over an RF interface in the same way as in a real cellular network.

3.5.1.1.1 LTE-M mode

The following table shows recommended test cases for conducted *LTE-M* signaling mode.

Mode	Test item	3GPP test ID	Band/ Channel	Temp/ Voltage	Signaling parameters	Expected result	Note
LTE-M TX	Maximum output power	6.2.2E	ALL/LMH	TYP/EXT	5 MHz, QPSK (RMC), Pmax	22 dBm	Pmax, 22 dBm ±2 dB (5 MHz, 6 RB)
	Frequency error	6.5.1E	ALL/MID	TYP/TYP		<±0.1 ppm	Pmax
	PUSCH EVM (RMS)	6.5.2E.1	ALL/LMH	TYP/EXT		<6%	Pmax, 3GPP limit <17.5%
	Adjacent channel leakage power ratio	6.6.2.3				>33 dB	Pmax, E-UTRA ACLR±1
	Spurious emissions (9 kHz to 12.75 GHz)	6.6.3.1	ALL/MID	TYP/TYP		<-33 dBm/1 MHz	Pmax, harmonics, spurious, noise
LTE-M RX	Reference sensitivity level	7.3	ALL/ALL			<-105 dBm	For faster measurement, channel raster *Low Mid High (LMH)*

Table 3: RF performance tests for conducted LTE-M signaling mode

Measuring receiver sensitivity for all channels is time-consuming but reveals any spurious or noise coupled to the nRF9160 antenna port.

The *Reference Measurement Channel (RMC)* used in the *LTE-M* mode is defined by the following *3GPP TS 36.101* annexes:

- Annex A.2.2.1.1-1b – *Reference Channels for QPSK with full/maximum RB allocation for UE UL category M1*
- Annex A.3.2-1b – *Fixed Reference Channel for Receiver Requirements (FDD and HD-FDD) –for CAT-M1*

3.5.1.1.2 NB-IoT mode

The following table shows recommended test cases for conducted *NB-IoT* signaling mode.

Mode	Test item	3GPP test ID	Band/ Channel	Temp/ Voltage	Signaling parameters	Expected result	Note
NB-IoT TX	Maximum output power	6.2.2F	ALL/LMH	TYP/EXT	15 kHz, QPSK, 12 SC, Pmax (RMC)	21 dBm	Pmax, 21 dBm ±2 dB (QPSK, 12 SC)
	Frequency error	6.5.1F	ALL/MID	TYP/TYP		<±0.1 ppm	Pmax
	NPUSCH EVM (RMS)	6.5.2F.1	ALL/LMH	TYP/EXT		<6%	Pmax, 3GPP limit <17.5%
	Adjacent channel leakage power ratio	6.6.2F.3				>33 dB	Pmax, E-UTRA ACLR±1
	Spurious emissions (9kHz to 12.75GHz)	6.6.3.1F.1	ALL/MID	TYP/TYP		<-33 dBm/1 MHz	Pmax, harmonics, spurious, noise
NB-IoT RX	Reference sensitivity level	7.3.1F	ALL/ALL			<-112 dBm	For faster measurement, channel raster *LMH*

Table 4: RF performance tests for conducted NB-IoT signaling mode

Measuring receiver sensitivity for all channels is time-consuming but reveals any spurious or noise coupled to the nRF9160 antenna port.

The *RMC* used in the *NB-IoT* mode is defined by the following *3GPP TS 36.101* annexes:

- Annex A.2.4 – *Reference Channels for UE UL category NB1*
- Annex A.3.2 -1c – *Fixed Reference Channel for Receiver Requirements (HD-FDD) without repetition –for CAT-NB1*

3.5.1.1.3 GPS mode

GPS testing is essential on the product level since the *GPS* RF front-end design, including *Low-Noise Amplifier (LNA)* and filtering, is the integrator's responsibility.

The following table shows recommended test cases for conducted *GPS* signaling mode. The expected results include the contribution of external *GPS LNA*.

Mode	Test item	Test specification/ ID	Band/ Channel	Temp/ Voltage	Signaling parameters	Expected result	Note
GPS RX	GPS sensitivity / CN0 (SNR)	NA	GPS	TYP/ TYP	GPS in receive mode GPS signal level -135 dBm	CN0>34 dB[1]	ARB signal generator can be used for *GPS* signal. The *GPS* CN0 data can be recorded from *UART* trace information. For details on CN0 data tracing, see nRF Connect SDK code examples.
	Adjacent frequency band selectivity	*ETSI EN 303 413 v1.1.1*			GPS in receive mode GPS signal level -128.5 dBm 1 satellite min	CN0 degradation <1 dB (vs. w/o blocker)	Requires *GPS* and blocker signal (AWGN) generators.
	Spurious emissions				GPS in receive mode	Below emissions limit	Limit: 30 MHz...1 GHz -57 dBm/100 kHz, 1 GHz... 8.3 GHz -47 dBm/1 MHz

Table 5: RF performance tests for conducted GPS signaling mode

Receiver blocking tests verify the *GPS* filtering's compliance against *GPS* blocking requirements in *ETSI EN 303 413 V1.1.1*.

Since LTE TX may cause intermodulation or harmonics in the external *GPS LNA* input, the LTE TX signal may require filtering on the *GPS* signal path. Other active components, such as *Integrated Circuit (IC)*s or LEDs, that are located near the LTE antenna may cause similar disturbance. These signal components may cause LTE radiated spurious tests to fail in certification. LTE TX and *GPS* RX are not active at the same time, and therefore the LTE TX signal does not interfere with *GPS* receiving.

3.5.1.2 Non-signaling mode

In the non-signaling mode, continuous TX or RX mode and burst mode TX can be used.

When using continuous TX, closed-loop power control is not active. This may cause TX power to drift. Drift may happen with long TX transmissions using over 10 dBm power levels. To correctly decode the

[1] Assuming that an external *LNA* is used. The external *LNA*'s *Noise Factor (NF)* is less than 2 dB, and minimum gain is 15 dB.

non-signaling mode TX signal, the RF tester must be set according to the system bandwidth defined in the **%XRFTEST** TX test command.

The non-signaling RX mode uses *Carrier Wave (CW)* signal for *Signal-to-Noise Ratio (SNR)* measurement and returns *SNR* and RSSI values for each measured frequency point.

The non-signaling mode *SNR* result can be converted to approximate sensitivity with the following formula:
`Sensitivity [dBm]` = *Prx_snr* `[dBm]` + `BB_snr [dB]` − *SNR_result* `[dB]`

where

Prx_snr
CW level from signal generator [dBm]. The power level should be -90 dBm or less at the antenna feed pad.

BB_snr
Required minimum *SNR* to reach 5% block error rate (BLER). For *LTE-M*, 0.5 dB can be used, and for *NB-IoT*, 1.5 dB can be used.

SNR_result
SNR measurement result [dB]

> **Note:** AFC correction should be performed to increase the accuracy of the RX *SNR* measurement. AFC correction can reduce the frequency error between nRF9160 and the used test equipment.

In the non-signaling mode, an RSSI scan test can be used to detect if noise from other sources, such as *IC*s or LEDs, is coupling to the LTE antenna RF path on the *Printed Circuit Board (PCB)*. The test is a similar sweep as a non-signaling receiver sensitivity *SNR* test but without a *CW* test signal from an external signal generator. The level of the test signal in the **XRFTEST** AT command should be set to -90 dBm to set the RX gain properly.

The **XRFTEST** parameters used in the non-signaling mode tests are defined in Production test features in nRF91 AT Commands Reference Guide.

3.5.1.2.1 LTE-M mode

The following table shows recommended test cases for conducted *LTE-M* non-signaling mode.

Mode	Test item	3GPP test ID	Band/ Channel	Temp/ Voltage	XRFTEST signal parameters	Expected result	Note
LTE-M TX	Maximum output power	6.2.2E	ALL/LMH	TYP/EXT	1.4 MHz, QPSK, 6 RB, Pout +25 dBm	21 dBm	Pmax, 21 dBm ±2 dB (1.4 MHz, 6 RB)
	Frequency error	6.5.1E	ALL/MID	TYP/TYP		<±0.1 ppm	Requires performing AFC correction. A supporting AT command is available in modem firmware v1.2.0 and later.
	PUSCH EVM (RMS)	6.5.2E.1	ALL/LMH	TYP/EXT		<6%	3GPP limit <17.5%
	Adjacent channel leakage power ratio	6.6.2.3				>33 dB	E-UTRA ACLR ±1
	Spurious emissions (9 kHz to 12.75 GHz)	6.6.3.1	ALL/MID	TYP/TYP		<-33 dBm/1 MHz	Harmonics, noise
LTE-M RX	Reference sensitivity level	7.3	ALL/ALL		CW level -90 dBm[2]	>15 dB SNR	Expected *SNR* at -90 dBm test signal (*CW*) level
	RSSI scan[3]	NA				RSSI < -105 dBm	Expected RSSI reading of average noise floor

Table 6: RF performance tests for conducted LTE-M non-signaling mode

3.5.1.2.2 NB-IoT mode

The following table shows recommended test cases for conducted *NB-IoT* non-signaling mode.

[2] Sets RX gain.
[3] To test noise floor.

Mode	Test item	3GPP test ID	Band/ Channel	Temp/ Voltage	XRFTEST signal parameters	Expected result	Note
NB-IoT TX	Maximum output power	6.2.2F	ALL/LMH	TYP/EXT	15 kHz, QPSK, 12 SC, Pout +25 dBm	21 dBm	Pmax, 21 dBm ±2 dB (QPSK, 12 SC)
	Frequency error	6.5.1F	ALL/MID	TYP/TYP		<±0.1 ppm	Requires performing AFC correction. A supporting AT command is available in modem firmware v1.2.0 and later.
	NPUSCH EVM (RMS)	6.5.2F.1	ALL/LMH	TYP/EXT		<6%	3GPP limit <17.5%
	Adjacent channel leakage power ratio	6.6.2F.3				>33 dB	E-UTRA ACLR ±1
	Spurious emissions (9 kHz to 12.75 GHz)	6.6.3.1F.1	ALL/MID	TYP/TYP		<-33 dBm/1 MHz	Harmonics, noise
NB-IoT RX	Reference sensitivity level	7.3.1F	ALL/ALL		CW level -90 dBm[4]	>21.5 dB SNR	Expected SNR at -90 dBm test signal (*CW*) level
	RSSI scan[5]	NA				RSSI <-111.5 dBm	Expected RSSI reading of average noise floor

Table 7: RF performance tests for conducted NB-IoT non-signaling mode

3.5.1.2.3 GPS mode

The following table shows recommended test cases for conducted *GPS* non-signaling mode.

[4] Sets RX gain.
[5] To test noise floor.

Mode	Test item	Test specification/ ID	Band/ Channel	Temp/ Voltage	XRFTEST signal parameters	Expected result	Note
GPS RX	GPS sensitivity / CN0 (SNR)	NA	GPS	TYP/TYP	CW level -100 dBm + extLNA gain dBm[6]	SNR >5 dB[7]	Requires *CW* signal generator

Table 8: RF performance tests for conducted GPS non-signaling mode

The recommended signal level for *GPS* mode testing is -100 dBm. The **%XRFTEST** AT command uses the signal level at the nRF9160 *GPS* port as an input parameter for the RX gain setting. Therefore, the **%XRFTEST** signal power parameter needs to include the level increase from the external *LNA*.

The following figure shows the recommended *GPS* input signal level for *GPS* non-signaling mode testing.

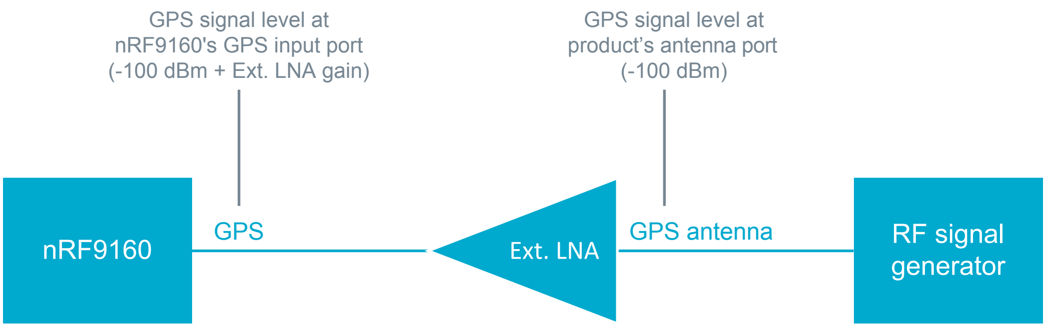


Figure 5: Recommended GPS input signal level for GPS non-signaling mode testing

3.5.2 RF radiated performance test

Radiated *Over-the-Air (OTA)* performance should also be verified. This test requires an anechoic RF chamber, and therefore it is usually done by a test house.

OTA tests performed in a certified laboratory are often required for product certifications or operator approvals. To get certified by a regulatory body, the device must pass RF exposure evaluation. Each regulatory body has their own set of permitted antenna radiation parameters. The maximum allowed power density limits for radiation can be used to derive the maximum gain limits for an antenna.

Before doing radiated testing in signaling mode, it is recommended to do passive antenna testing. Passive antenna tests ensure that antenna efficiency and radiation pattern are at the expected performance level. In addition to signaling mode, radiated testing can be done on device level using the non-signaling mode controlled by AT commands.

For more information on radiated RF testing, see nWP033 - nRF9160 Antenna and RF Interface Guidelines.

3.5.2.1 Signaling mode

In the signaling mode, a connection is established towards the tester, and nRF9160 is controlled over an RF interface in the same way as in a real cellular network.

3.5.2.1.1 LTE-M mode

The following table shows recommended test cases for radiated *LTE-M* signaling mode.

[6] Sets RX gain.
[7] Assuming external *GPS LNA* with *NF* < 2 dB and gain > 15 dB.
[8] Equivalent to conducted TX maximum output power.
[9] Equivalent to conducted TX spurious emissions.

Mode	Test item	Test specification/ID	Requirement	Note
LTE-M TX	Total Radiated Power (TRP)[8]	*CTIA Test Plan for Wireless Device Over-the-Air Performance v3.8.2, Radiated Power, 5.15 LTE Category M1*	Undefined by CTIA for *LTE-M*. Operators have their own specifications for radiated performance.	For analyzing a product's radiated performance or validating conformance with operator requirements
	Radiated spurious emissions[9]	*ETSI EN 301 908 V11.1.7, chapter 4.2.2 Radiated emissions (UE)*	30 MHz ≤f < 1000 MHz -36 dBm/100 kHz 1 GHz ≤f < 12.75 GHz -30 dBm/1 MHz	For CE certification
	Radiated spurious emissions[9]	*FCC CFR 47* Parts 22, 24 and 27 §27.53: B12,B13 §22.905 &§22.917: B5 §24.238 & §27.53: B2, B4,B25	Versatile collection of emission limits	For FCC/ISED certification
LTE-M RX	Total Isotropic Sensitivity (TIS)[10]	*CTIA Test Plan for Wireless Device Over-the-Air Performance v3.8.2, Receiver Performance, 6.20 LTE Category M1*	Undefined by CTIA for *LTE-M*. Operators have their own specifications for radiated performance.	For analyzing a product's radiated performance or validating conformance with operator requirements

Table 9: RF performance tests for radiated LTE-M signaling mode

Note: Radiated spurious emissions include all spurious content from the end product, for example, from *IC*s and LEDs and may differ from conducted performance.

Note: The reuse of nRF9160's FCC or ISED certificate may not be valid if the product's antenna performance differs from the performance of the antenna used in the nRF9160 certificate.

3.5.2.1.2 NB-IoT mode

The following table shows recommended test cases for radiated *NB-IoT* signaling mode.

[10] Equivalent to conducted RX reference sensitivity level.

Mode	Test item	Test specification/ID	Requirement	Note
NB-IoT TX	Total Radiated Power (TRP)[11]	Undefined by CTIA for *NB-IoT*. Similar to *CTIA Test Plan for Wireless Device Over-the-Air Performance v3.8.2, Radiated Power, 5.15 LTE Category M1*	Undefined by CTIA for *NB-IoT*. Operators have their own specifications for radiated performance.	For analyzing a product's radiated performance or validating conformance with operator requirements
	Radiated spurious emissions[12]	*ETSI EN 301 908 V11.1.7, chapter 4.2.2 Radiated emissions (UE)*	30 MHz ≤f < 1000 MHz -36 dBm/100 kHz 1 GHz ≤f < 12.75 GHz -30 dBm/1 MHz	For CE
	Radiated spurious emissions[12]	*FCC CFR 47* Parts 22, 24 and 27 §27.53: B12,B13 §22.905 &§22.917: B5 §24.238 & §27.53: B2, B4,B25	Versatile collection of emission limits	For FCC/ISED
NB-IoT RX	Total Isotropic Sensitivity (TIS)[13]	Undefined by CTIA for *NB-IoT*. Similar to *CTIA Test Plan for Wireless Device Over-the-Air Performance v3.8.2, Receiver Performance, 6.20 LTE Category M1*	Undefined by CTIA for *NB-IoT*. Operators have their own specifications for radiated performance.	For analyzing a product's radiated performance or validating conformance with operator requirements

Table 10: RF performance tests for radiated NB-IoT signaling mode

Note: Radiated spurious emissions include all spurious content from the end product, for example, from *IC*s and LEDs and may differ from conducted performance.

Note: The reuse of nRF9160's FCC or ISED certificate may not be valid if the product's antenna performance differs from the performance of the antenna used in the nRF9160 certificate.

3.5.2.1.3 GPS mode

A simple test to evaluate *GPS* sensitivity is to measure the CN0 level in radiated mode.

The following table shows recommended test cases for radiated *GPS* signaling mode.

[11] Equivalent to conducted TX maximum output power.
[12] Equivalent to conducted TX spurious emissions.
[13] Approximation of conducted RX reference sensitivity level when scaled 10 log (0.18/1.08) + 1 dB.

Mode	Test item	Test specification/ID	Requirement	Note
GPS RX	Radiated Sensitivity	*CTIA Test Plan for Wireless Device Over-the- Air Performance v3.8.2, Appendix R, Stand-Alone GNSS Test Methodology and Test Procedure*	Based on end product requirements or targets	Radiated noise coupling from, for example, *ICs* or LEDs may cause desensitization to the *GPS* receiver that is impossible to test in other than radiated signaling mode

Table 11: RF performance tests for radiated GPS signaling mode

To achieve good *GPS* performance, the *GPS* antenna requires careful design and verification. For example, an upper hemisphere *Right Hand Circular Polarization (RHCP)* type of antenna can be used to improve the antenna's performance. For more information, see nWP033 - nRF9160 Antenna and RF Interface Guidelines.

3.5.2.2 Non-signaling mode

In the non-signaling mode, continuous TX or RX and burst mode TX can be used.

When doing an RSSI scan test, verify first the RSSI reference noise floor level as a function of frequency with an antenna feed pad that is terminated to 50 Ω. Then, connect the antenna and repeat the test. The expected measured RSSI variation is less than 2 dB. The test result may be heavily impacted by cables that are connected to the *DUT*, for example, for AT command control. This can be avoided by controlling the *DUT* wirelessly through Bluetooth. The test may also reveal noise that originates from some other source than the *DUT*, for example, an LTE base station nearby.

For more information, see Non-signaling mode on page 15.

3.5.2.2.1 LTE-M mode

The following table shows recommended test cases for radiated *LTE-M* non-signaling mode.

Mode	Test item	Test specification/ID	Expected result	Note
LTE-M TX	LTE antenna efficiency and radiation pattern at TX frequencies	See nWP033 - nRF9160 Antenna and RF Interface Guidelines	>50%	For analyzing antenna efficiency by using an RF signal generator as the signal source
	Total Radiated Power (TRP)		Conducted TX power - antenna efficiency	For analyzing antenna efficiency by using *DUT*-internal TX as the signal source
	LTE TX isolation to GPS LNA input		Isolation >30 dB	Isolation from LTE antenna to *GPS LNA* input at LTE TX frequency
LTE-M RX	LTE antenna efficiency and radiation pattern at RX frequencies		>50%	
	RSSI scan[15]	Signal level -90 dBm[14]	RSSI < -105 dBm	Expected RSSI reading of average noise floor

Table 12: RF performance tests for radiated LTE-M non-signaling mode

3.5.2.2.2 NB-IoT mode

The following table shows recommended test cases for radiated *NB-IoT* non-signaling mode.

Mode	Test item	Test specification/ID	Expected result	Note
NB-IoT TX	LTE antenna efficiency and radiation pattern at TX frequencies	See nWP033 - nRF9160 Antenna and RF Interface Guidelines	>50%	For analyzing antenna efficiency by using an RF signal generator as the signal source
	Total Radiated Power (TRP)		Conducted TX power - antenna efficiency	For analyzing antenna efficiency by using *DUT*-internal TX as the signal source
	LTE TX isolation to GPS LNA input		Isolation >30 dB	Isolation from LTE antenna to the *GPS LNA* input at LTE TX frequency
NB-IoT RX	LTE antenna efficiency and radiation pattern at RX frequencies		>50%	
	RSSI scan[17]	Signal level -90 dBm[16]	RSSI < -112 dBm	Expected RSSI reading of average noise floor

Table 13: RF performance tests for radiated NB-IoT non-signaling mode

[14] Sets RX gain.
[15] To test noise floor.

3.5.2.2.3 GPS mode

The following table shows recommended test cases for radiated *GPS* non-signaling mode.

Mode	Test item	Test specification/ID	Expected result	Note
GPS RX	*GPS* antenna efficiency and radiation pattern at *GPS* frequency	See nWP033 - nRF9160 Antenna and RF Interface Guidelines	>50% (target >70%)	For a device with predictable orientation when in normal use, a *RHCP* antenna is recommended

Table 14: RF performance tests for radiated GPS non-signaling mode

3.6 Controlling external RF components

nRF9160 supports controlling external RF components, for example the antenna tuner, with the MAGPIO pins or *MIPI RF Front-End Control Interface (RFFE)* serial interface.

3.6.1 Example of configuring nRF9160 MAGPIO for external device

MAGPIO pins can be configured with the Nordic-proprietary **%XMAGPIO** AT command.

For information on the **%XMAGPIO** AT command options, see MAGPIO configuration %XMAGPIO in nRF91 AT Commands Reference Guide.

For an example of a device using MAGPIO pins for LTE antenna tuning, see Nordic Thingy:91. For Nordic Thingy:91's hardware files, see Hardware files.

3.6.2 Example of configuring nRF9160 MIPI RFFE for external device

Commands in this section need to be given only after device power-up or in device production. If the **AT+CFUN=0** AT command is given in the production phase, it stores the given AT command's content to nRF9160's non-volatile flash memory.

An *MIPI RFFE* device can be configured for nRF9160 with the Nordic-proprietary **%XMIPIRFFEDEV** and **%XMIPIRFFECTRL** AT commands.

3.6.2.1 Initial configuration of RFFE device

To introduce a device to nRF9160, the **%XMIPIRFFEDEV** AT command is given with the unique properties of the device.

The MIPI register content in registers 0x1C, 0x1D, and 0x1E can be found in the device datasheet. Select an ID number for the <dev_id> parameter of the **%XMIPIRFFEDEV** AT command.

The following command syntax is an example of the initial configuration of an RFFE device:

```
AT%XMIPIRFFEDEV=1,6,41,52,184
```

The command parameters and their values in the example are the following:

[16] Sets RX gain.
[17] To test noise floor.

Parameter name	Parameter description	Value in example	Value description
<dev_id>	Selectable identification number for the device. Non-zero. Valid range 1–255. The given dev_id is used with the **XMIPIRFFECTRL** AT command.	1	
<def_usid>	A 4-bit default *Unique Slave Identifier (USID)* of the *MIPI RFFE* device. Typically, 7 for antenna tuners (as suggested by MIPI).	6	The value from the MIPI register 0x1F [3:0].
<prod_id>	An 8-bit PRODUCT_ID of the *MIPI RFFE* device. Only used if automatic reprogramming of the *USID* is needed. EXT_PRODUCT_ID is not supported.	41	The value from the MIPI register 0x1D [7:0].
<man_id>	A 10-bit MANUFACTURER_ID of the *MIPI RFFE* device. Only used if automatic reprogramming of the *USID* is needed.	52	The value from the MIPI register 0x1E [7:0].
<pm_trig>	An 8-bit content for PM_TRIG (address 0x1C) state.	184	Value to write to MIPI register 0x1C.

Table 15: Parameters in initial configuration example

The *MIPI RFFE* bus supports 15 unique *USID* values. If the given device *USID* conflicts with any *SiP* internal *USID*, nRF9160 automatically reprograms the device *USID* to the first free value. This process requires a product ID and manufacturer ID defined in the **%XMIPIRFFEDEV** AT command.

For more information on introducing a device to nRF9160 using the **%XMIPIRFFEDEV** AT command, see SiP-external MIPIRFFE device introduction %XMIPIRFFEDEV in nRF91 AT Commands Reference Guide.

3.6.2.2 Configuration of RFFE device control

The external *MIPI RFFE* control in nRF9160 supports configuring the RFFE device for four different phases of RF operation. The phases are initializing (INIT), start receiving or transmitting (ON), stop receiving or transmitting (OFF), and going to sleep (PWROFF).

The phases of RF operation are described in the following figure.

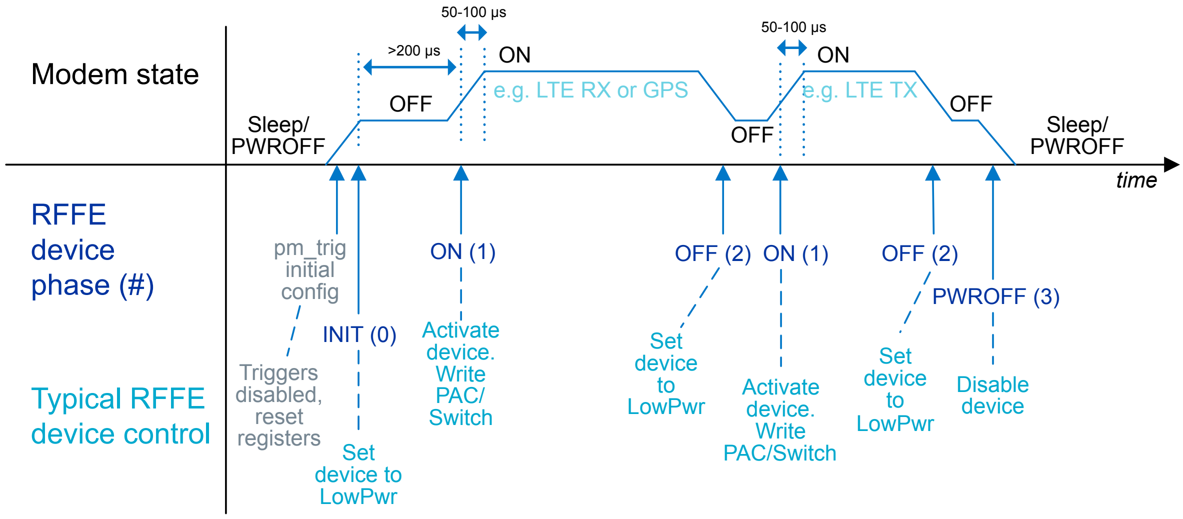


Figure 6: RFFE device control and timing in different phases

In each phase, up to four register writes can be defined to the addresses of the RFFE slave device using the **%XMIPIRFFECTRL** AT command. Defining register writes to all use cases is not mandatory. In the ON phase, two out of the four register values are tabulated based on the control action to be applied.

For the generic format of the **%XMIPIRFFECTRL** AT command and information on the RF operation phases, see SiP-external MIPIRFFE device control configuration %XMIPIRFFECTRL in nRF91 AT Commands Reference Guide.

3.6.2.2.1 Initializing (INIT)

When the internal LTE radio of nRF9160 wakes up, the initialization phase is applied to the external RFFE device to prepare the RFFE device for transmitting or receiving. The device is set to active low power mode and triggers are disabled. Initialization is needed to avoid long start-up times in later RFFE device control phases.

The syntax of the INIT phase is the following:

```
%XMIPIRFFECTRL=<dev_id>,0,<n>,<address_0>,<data_0>,…,<address_n-1>,<data_n-1>
```

The following command example initializes an RFFE device with the **%XMIPIRFFECTRL** AT command:

```
AT%XMIPIRFFECTRL=1,0,1,28,184
```

The command parameters and their values in the example are the following:

Parameter name	Parameter description	Value in example	Value description
<dev_id>	The identification number of the *MIPI RFFE* device given when it was introduced using **`%XMIPIRFFEDEV`**	1	
<use_case#>	Number of the phase. INIT = 0, ON = 1, OFF = 2, PWR_OFF = 3. All numbers must be given as decimals (hexadecimals not allowed).	0	INIT phase
<n>	The number of address/data pairs. Valid values are 0, 1, 2, 3, 4. If the value is 0, all the following fields must be omitted.	1	Number of register writes in this command
<address_x>	The 8-bit address of the internal register in *MIPI RFFE* device. x = 0, ..., n−1.	28	Address of PM_TRIG register (= 0x1C)
<data_x>	The 8-bit data to be written to <address_x>. x = 0, ..., n−1.	184	Value to write to register address 28.

Table 16: Parameters in initialization example

The writes in the initialization phase are applied when the modem wakes up. This happens when an initial cell search is started or after a *DRX*, *Extended Discontinuous Reception (eDRX)*, or *PSM* sleep period.

3.6.2.2.2 Starting receiving or transmitting (ON)

When starting to receive or transmit, the configuration of the ON phase is applied to the RFFE device.

The syntax of the ON phase is the following:

```
%XMIPIRFFECTRL=<dev_id>,1,n,<act_addr_0>,<act_data_0>,<act_addr_n-1>,<act_data_n-1>,<k>,
<addr_0>,<addr_1>,<data_0_0>,<data_1_0>,<freq_0>,...,<data_0_k-1>,<data_1_k-1>,<freq_k-1>
```

The ON phase has two controls: activation and dynamic registers.

- Activation – A frequency-agnostic control that can be used to activate a device instead of initialization if the start-up time is short.
- Dynamic registers – Two registers can be controlled based on frequency. In the following example, REG_X and REG_Y are tabulated registers with frequency dependent values. Real device register addresses and register names for REG_X and REG_Y are defined in the device datasheet. In the example, letters A-F replace the 8-bit integer decimal values that need to be determined in the design and verification phase.

The following table is an example of what a control table could look like:

RF frequency	REG_X	REG_Y
0–800 MHz	A	B
801–1600 MHz	C	D
1601–2200 MHz	E	F

Table 17: Example of RF frequency-based control in the ON phase

The following command example starts receiving or transmitting with the **%XMIPIRFFECTRL** AT command. It has three frequency ranges that control two registers each and one activation register write.

```
AT%XMIPIRFFECTRL=1,1,1,28,56,3,1,2,A,B,800,C,D,1600,E,F,2200
```

The command parameters and their values are the following:

Parameter name	Parameter description	Value in example	Value description
<dev_id>	The identification number of the *MIPI RFFE* device given when it was introduced using **%XMIPIRFFEDEV**.	1	
<use_case#>	Number of the use case. INIT = 0, ON = 1, OFF = 2, PWR_OFF = 3. All numbers must be given as decimals (hexadecimals not allowed).	1	ON phase
<n>	The number of activation register address-data pairs. Valid values are 0, 1, 2. If n =0, act_addr_0/1 and act_data_0/1 must be omitted.	1	Number of frequency agnostic activation registers
<act_addr_x>	Optional 8-bit address of the first register whose value is set to e.g. activate device. This is written each time RF starts.	28	Register address to write
<act_data_x>	Optional 8-bit data for the register in <act_addr_x>.	56	Value to write into address 28
<k>	The number of frequencies in the configuration. Valid values are 0–64. If k = 0, all the following fields must be omitted.	3	Number of rows in frequency table
<addr_0>	The 8-bit address of the first register, whose value is changed on the basis of RF frequency.	1	Address of REG_X (the first register to write)
<addr_1>	The 8-bit address of the other register, whose value is changed on the basis of RF frequency. If addr_1 == addr_0, then only <data_0_y> is written.	2	Address of REG_Y (the second register to write)
<data_0_0>	The 8-bit data for the register in <addr_0>, if frequency is smaller than or equal to <freq_0>.	A	Value to write to REG_X if RF frequency is 0–800 MHz
<data_1_0>	The 8-bit data for the register in <addr_1>, if frequency is smaller than or equal to <freq_y>.	B	Value to write to REG_Y if RF frequency is 0–800 MHz
<freq_0>	The frequency in MHz (integer), to which the current RF frequency is compared.	800	High limit MHz of first frequency row
<data_0_1>	The 8-bit data for the register in <addr_0>, if frequency is smaller than or equal to <freq_1>.	C	Value to write to REG_X if RF frequency is 801–1600 MHz
<data_1_1>	The 8-bit data for the register in <addr_1>, if frequency is smaller than or equal to <freq_y>.	D	Value to write to REG_Y if RF frequency is 801–1600 MHz

Parameter name	Parameter description	Value in example	Value description
<freq_1>	The frequency in MHz (integer), to which the current RF frequency is compared.	1600	High limit MHz of second frequency row
<data_0_2>	The 8-bit data for the register in <addr_0>, if frequency is smaller than or equal to <freq_2>.	E	Value to write to REG_X if RF frequency is 1601–2200 MHz
<data_1_2>	The 8-bit data for the register in <addr_1>, if frequency is smaller than or equal to <freq_2>.	F	Value to write to REG_Y if RF frequency is 1601–2200 MHz
<freq_2>	The frequency in MHz (integer), to which the current RF frequency is compared.	2200	High limit MHz of third frequency row

Table 18: Parameters in starting receiving example

There can be up to 64 rows in the frequency table, which can be useful in achieving high-resolution antenna tuning.

The writes in the ON command are applied at least 50 µs before modem transmission or reception. The ON command writes are applied also in the frequency hopping mode that may be used in the *LTE-M* operation mode.

3.6.2.2.3 Stopping receiving or transmitting (OFF)

In the OFF phase, the device is returned to active low power mode to minimize power consumption when RF has stopped.

The syntax of the OFF phase is the following:

```
%XMIPIRFFECTRL=<dev_id>,2,<n>,<address_0>,<data_0>,…,<address_n-1>,<data_n-1>
```

The following command example stops receiving or transmitting with the **%XMIPIRFFECTRL** AT command:

```
AT%XMIPIRFFECTRL=1,2,1,28,184
```

The command parameters and their values in the example are the following:

Parameter name	Parameter description	Value in example	Value description
<dev_id>	The identification number of the *MIPI RFFE* device given when it was introduced using **%XMIPIRFFEDEV**.	1	
<use_case#>	Number of the use case. INIT = 0, ON = 1, OFF = 2, PWR_OFF = 3. All numbers must be given as decimals (hexadecimals not allowed).	2	OFF phase
<n>	The number of address/data pairs. Valid values are 0, 1, 2, 3, 4. If the value is 0, all the following fields must be omitted.	1	Number of register writes in this command
<address_x>	The 8-bit address of the internal register in MIPI RFFE device. x = 0, ..., n−1.	28	Address of the PM_TRIG register (= 0x1C)
<data_x>	The 8-bit data to be written to <address_x>. x = 0, ..., n−1.	184	Value to write to register address 28

Table 19: Parameters in stopping receiving or transmitting example

The writes in the OFF phase are applied when RF is turned off. This happens between reception and transmission bursts. During longer breaks in modem usage, the modem is put to sleep and the RFFE device is set to Going to sleep (PWROFF) on page 31.

3.6.2.2.4 Going to sleep (PWROFF)

In the PWROFF phase, the antenna tuner is reset back to the STARTUP state to minimize power consumption when RF is disabled or sleeping. Also, VIO output voltage is turned off. The writes in the PWROFF phase are applied when RF is disabled or put to sleep. This happens, for example, in a *DRX*, *eDRX*, or *PSM* sleep period.

The syntax of the PWROFF phase is the following:

```
%XMIPIRFFECTRL=<dev_id>,3,<n>,<address_0>,<data_0>,…,<address_n-1>,<data_n-1>
```

The following command example sets the RFFE device to sleep using the **%XMIPIRFFECTRL** AT command:

```
AT%XMIPIRFFECTRL=1,3,1,28,184
```

The command parameters and their values in the example are the following:

Parameter name	Parameter description	Value in example	Value description
<dev_id>	The identification number of the *MIPI RFFE* device given when it was introduced using **%XMIPIRFFEDEV**.	1	
<use_case#>	Number of the use case. INIT = 0, ON = 1, OFF = 2, PWR_OFF = 3. All numbers must be given as decimals (hexadecimals not allowed).	3	PWROFF phase
<n>	The number of address/data pairs. Valid values are 0, 1, 2, 3, 4. If the value is 0, all the following fields must be omitted.	1	Number of register writes in this command
<address_x>	The 8-bit address of the internal register in *MIPI RFFE* device. x = 0, ..., n−1.	28	Address of the PM_TRIG register (= 0x1C)
<data_x>	The 8-bit data to be written to <address_x>. x = 0, ..., n−1.	184	Value to write to register address 28

Table 20: Parameters in going to sleep example

3.6.2.2.5 Summary

The following AT commands can be given in device production to store data to the non-volatile memory of nRF9160. This must be done after flashing the modem firmware.

```
AT%XMIPIRFFEDEV=1,6,41,52,184
AT%XMIPIRFFECTRL=1,0,1,28,184
AT%XMIPIRFFECTRL=1,1,1,28,56,3,1,2,A,B,800,C,D,1600,E,F,2200
AT%XMIPIRFFECTRL=1,2,1,28,184
AT%XMIPIRFFECTRL=1,3,1,28,184
AT+CFUN=0
```

Alternatively, the same commands can be given by application software at boot. In this case, `AT+CFUN=0` can be omitted.

After the commands have been given, the runtime control of the device is handled automatically by nRF9160.

3.6.2.2.6 Reading configuration

The existence of the configuration data can be checked with the **%XMIPIRFFEDEV** read AT command.

Syntax:

```
AT%XMIPIRFFEDEV?
```

The command returns the configuration data given for a device using the **%XMIPIRFFEDEV** AT command and the use-case specific **%XMIPIRFFECTRL** AT command.

3.6.2.2.7 Deleting configuration

Device configuration and phase control can be deleted from the nRF9160 memory using the **%XMIPIRFFEDEV** AT command.

The following command example deletes the configuration with the **%XMIPIRFFEDEV** AT command:

```
AT%XMIPIRFFEDEV=1
```

The command parameter and its value in the example are the following:

Parameter name	Parameter description	Value in example
<dev_id>	The identification number of the *MIPI RFFE* device given when it was introduced using **%XMIPIRFFEDEV**	1

Table 21: Parameters in deleting configuration example

4 Production test

The test flow described in this section provides an example of the production test process for a product based on nRF9160. nRF9160 is fully tested and calibrated in the Nordic Semiconductor production line. The main focus of a product-level production test is checking for assembly related errors.

The test flow should be optimized for the specific needs of a product. A detailed test plan requires thorough knowledge of the product hardware and should be defined accordingly. The following figure shows an example of the test flow in production.

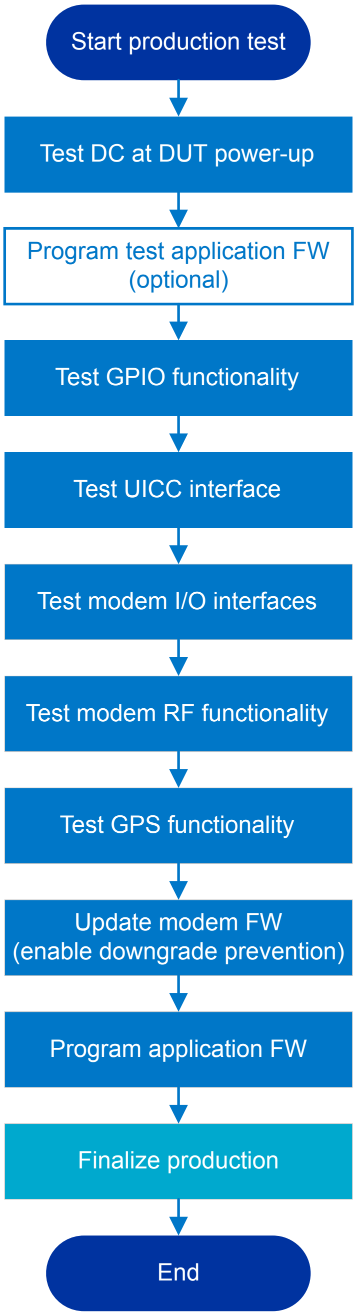


Figure 7: Example of test flow in production

4.1 DC testing at DUT power-up

If test points are available for measurement, voltage levels can be obtained from the **VDD**, **VDD_GPIO**, and **DEC0** pins. Expected values for these parameters are shown in Table 1: Voltage levels of VDD, VDD_GPIO, and DEC0 on page 8.

4.2 Programming test application

A dedicated application firmware that is optimized for testing can be used in production. Alternatively, the application firmware can contain special functions for test purposes. The application firmware's test features can speed up the test process significantly. This should be considered at an early stage of product development.

For information on developing and programming application firmware, see nRF Connect SDK.

4.3 Testing GPIO functionality

The functionality of the GPIO pins can be tested in different ways.

- Input mode test – Driving external signal and reading corresponding pin status from nRF9160 registers.
- Output mode test – Setting pin high or low from nRF9160 and measuring signal level with external test equipment.
- Input leakage test – Disconnecting pins and measuring leakage current with and without voltage bias.

In most cases, application firmware is the most convenient way to control the GPIO pins state. It can be optimized to test only the needed pins or to run a dedicated test sequence with a test command.

The states of the GPIO pins can be controlled also with the *SWD* debug interface. For more information, see Controlling GPIO pins with SWD on page 8.

4.4 Verifying UICC interface status

The functioning of the *UICC* interface can be verified with a *UICC* or by measuring the pin states with suitable test equipment.

4.4.1 Testing with UICC

If a *UICC* is available during production testing, the functioning of the interface can be verified by checking the card status after initialization.

> **Note:** The *UICC* used in production tests must be a test *SIM*. If an operator *SIM* is used, it may create an unwanted connection to the LTE network and start data transfer autonomously.

Modem firmware v1.1.3 and later require the *UICC* to be activated with the **+CFUN** AT command before the *UICC* status can be read. The *UICC* is activated with the command parameter 41. For more information on the **+CFUN** AT command, see Functional mode +CFUN in nRF91 AT Commands Reference Guide.

> **Note:** In the B1A hardware version, the modem firmware needs to be updated before this test.

The preprogrammed *PTI* modem firmware does not support *UICC* initialization. When using the *PTI* modem firmware, the **%XGPIOTEST** AT command can be used to test the *UICC* interface functionality.

The result of the *UICC* initialization can be asked with the **%XSIM** AT command.

The following command example reads the *UICC* state:

```
AT%XSIM?
   %XSIM: 1 // State = 1, UICC initialization OK
   OK
```

For more information on the **%XSIM** AT command, see UICC state %XSIM in nRF91 AT Commands Reference Guide.

Note: nRF9160 supports only *UICC* class C operation with 1.8 V nominal voltage.

4.4.2 Testing UICC interface as GPIO

The *UICC* interface can be tested by controlling the *UICC* pins with the **%XGPIOTEST** AT command and checking the pin states.

Each pin in the *UICC* interface can be set to the output mode and to the logic low state (0 V) or to the logic high state (1.8 V). The pins are **SIM_RST** (pin 43), **SIM_DET** (pin 45), **SIM_CLK** (pin 46), **SIM_IO** (pin 48), and **SIM_1V8** (pin 49). The pin voltage can then be measured with external test equipment. Alternatively, the pins can be set to the input state and the pin status can be read. The result of the test can be compared to an externally set level. Some of the *UICC* pins are unidirectional, supporting testing only in a predefined mode.

Note: The **%XGPIOTEST** AT command is supported by modem firmware pti_v1.1.1 and later.

For information on each pin's control options and the **%XGPIOTEST** AT command, see Modem GPIO functionality test %XGPIOTEST in nRF91 AT Commands Reference Guide

4.5 Testing modem I/O interface

nRF9160 contains the COEX[0:2], MAGPIO[0:2], and MIPI RFFE I/O interfaces for specific modem control, such as an antenna tuner control. The need to test these interfaces depends on the product specific configuration and should be planned accordingly.

For details on the pin configurations, see Controlling external RF components on page 24 and nRF91 AT Commands Reference Guide.

4.5.1 MAGPIO interface

If MAGPIO pins are used for RF front-end controls, the testing of the pin functions can be covered by RF functionality tests. In that case, dedicated tests are not needed.

For an example, see Antenna presence DC test on page 42.

4.5.2 MIPI RFFE interface

nRF9160 offers an MIPI serial bus for external devices. The *MIPI RFFE* contains a digital serial bus (SCLK and SDATA) and 1.8 V output (VIO). VIO is enabled when the modem is active and switched off when not needed. VIO output voltage can be measured when *MIPI RFFE* is active.

The *MIPI RFFE* interface is indirectly tested during RF functionality testing when the test cases cover all functional states of the external MIPI device. For more information on the nRF9160 *MIPI RFFE* interface, see nWP037 - nRF9160 Hardware Design Guidelines.

4.5.3 COEX interface

nRF9160 has three COEX I/O pins. For details on each pin's function, see LTE modem coexistence interface in nRF9160 Product Specification.

The COEX0 function can be configured with the **%XCOEX0** AT command. If COEX0 is configured for *GPS LNA* control, its functionality can be verified in *GPS* RX testing.

COEX2 can be monitored during RF TX testing and checked that the pin line is changing states. For more information on configuration options, see COEX0 pin control configuration %XCOEX0 in nRF91 AT Commands Reference Guide.

The COEX interface can be tested also with the **%XGPIOTEST** AT command that is supported by the *PTI* modem firmware. Each pin can be set to the output mode and to the logic low state (0 V) or to the logic high state (**VDD_GPIO**). The pin voltage can then be measured with external test equipment. Alternatively, the pins can be set to the input state and the pin status can be read. The result of the test can be compared to an externally set level.

For more information on the **%XGPIOTEST** AT command, see Modem GPIO functionality test %XGPIOTEST in nRF91 AT Commands Reference Guide.

> **Note:** The **%XGPIOTEST** AT command is supported by the *PTI* modem firmware pti_v1.1.1 and later.

4.6 Modem RF functionality

nRF9160 is fully calibrated and does not require any additional RF calibration. It is enough to verify successful assembly and soldering. For this purpose, nRF9160 supports the Nordic-proprietary **%XRFTEST** RF test AT command. Testing with three of the main test modes for RF performance, RX, TX, and *GPS SNR*, is supported.

To confirm the LTE RF functionality, usually testing either TX or RX is enough. For more information, see RX functionality test on page 38 and TX functionality test on page 39.

The support for the AT command-based test mode is intended for non-signaling RF testing and allows the use of lower cost test equipment, such as a spectrum analyzer and RF signal generator. The following figures show alternative setups for RF testing.

In the setups in Figure 8: Non-signaling RF test setup for LTE and GPS RX mode testing on page 37, Figure 9: Non-signaling RF test setup supporting both TX and RX testing on page 38, and Figure 10: Non-signaling RF test setup using RF tester on page 38, the RF attenuator is intended to stabilize RF impedance seen by the nRF9160 antenna port due to test fixture and cabling. For example, an attenuator of 6-10 dB can be used.

The setup in the following figure supports only RX mode testing.

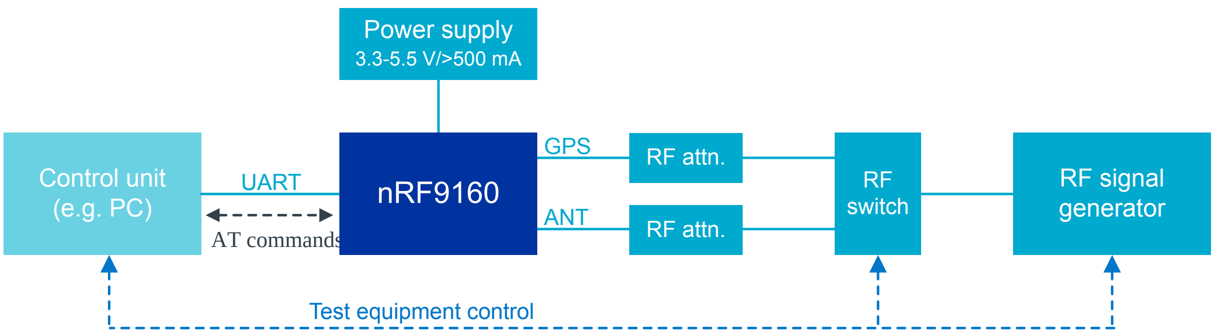


Figure 8: Non-signaling RF test setup for LTE and GPS RX mode testing

The setup in the following figure contains capability for both LTE TX and RX testing.

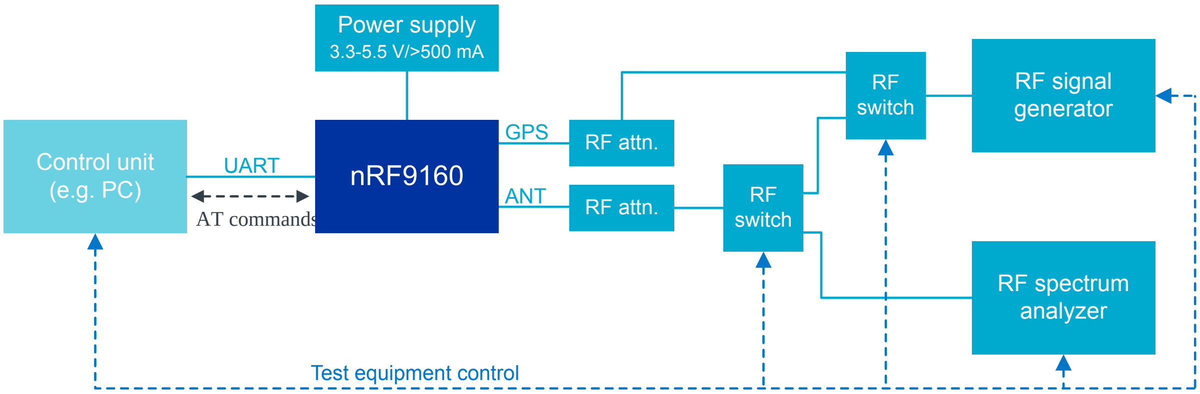


Figure 9: Non-signaling RF test setup supporting both TX and RX testing

The setup in the following figure uses a non-signaling LTE tester for more advanced measurements.

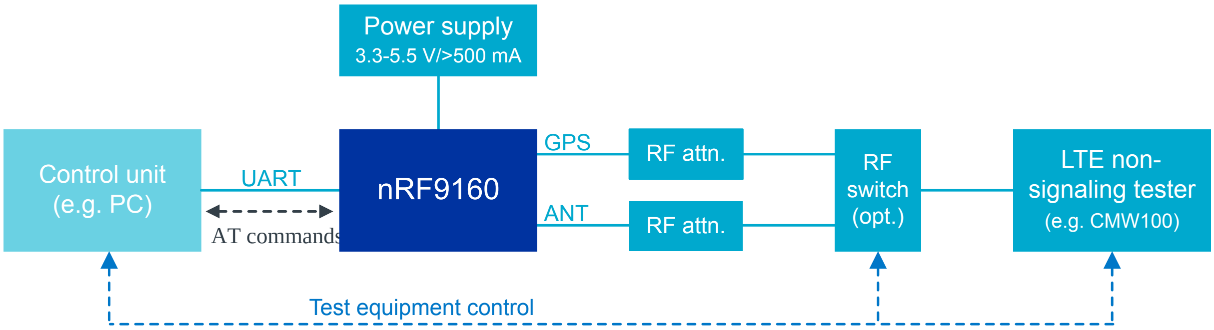


Figure 10: Non-signaling RF test setup using RF tester

The need for an RF switch or separate RF generator for *GPS* depends on the selected tester and the amount of parallel test setups.

The recommended voltage for the power supply is a minimum of 3.3 V for RF 3GPP compliancy. It is recommended to use a common timebase reference clock for all RF equipment if several sets of RF test equipment are used in the test setup.

For information on RF performance related test modes and other supported test capabilities, see nRF91 AT Commands Reference Guide.

4.6.1 RX functionality test

The **%XRFTEST** RX test enables the RF receiver with the given parameters and returns the result of the antenna power measurement or *SNR*. The reported parameter is set by the <test> parameter following the **%XRFTEST** AT command. OFF <operation> disables the RF receiver.

The recommended signal level for RX testing is -90 dBm. The expected *SNR* with this signal level is normally more than 16 dB.

AFC correction can be performed to increase the accuracy of the *SNR* measurement. AFC correction can compensate the frequency error between nRF9160 and the used test equipment. AFC measurement and setting are supported by modem firmware v1.2.x and later.

> **Note:** The reported *SNR* is very sensitive to external RF disturbance that may be present in the test environment. An RF shielded chamber is recommended as a stable test environment. A known device, such as a golden unit, can be used as a reference to confirm the validity of the test result.

The value of the power measured at the antenna port is given in the q8 (dBm) format. Dividing the result by 2^8 = 256 gives the dBm value of the antenna power.

The following command example executes an RX signal level (RSSI) test:

```
%XRFTEST=0,1,1,21400,-65,0 // RX ON (B1,2140.0MHz,-65dBm,NB1 mode)
%XRFTEST: -17002    // Result: -17002/256 = -66.4dBm
OK

%XRFTEST=0,0    // RX OFF
OK
```

The measured *SNR* is given in the q4 (dB) format. Dividing the result by 2^4 = 16 gives the dB value of the antenna power. This measurement reports both the *SNR* and RSSI values.

The following command example executes an RX *SNR* test:

```
%XRFTEST=3,1,1,21400,-65,1,1 // RX ON (B1,2140.0MHz,-65dBm,M1 mode, AFC correction enabled)
%XRFTEST: 496,-17002 // Res: 496/16=31dB, -17002/256=-66.4dBm
OK

%XRFTEST=0,0 // RX OFF
OK
```

The input parameters of the RX functionality test are described in the following table:

Parameter name	Parameter description	Value	Value description
<param0>	3GPP band number	1–66	Bands supported by nRF9160
<param1>	Frequency 100 kHz raster	6000–22000	Corresponds to 600–2200 MHz
<param2>	Signal level at antenna	–127 to –25	Signal level at the nRF9160 antenna input (dBm)
<param3>	System mode	0–1	NB1 = 0 M1 = 1
<param4>	Enabling AFC correction during *SNR* test	0–1	Enable and disable AFC correction

Table 22: Input parameters of RX functionality test

The signal level at antenna <param2> is used to set the receiver gain. It is recommended to set it to equal to the expected signal level at the nRF9160 antenna input.

For bands supported by nRF9160, see nRF9160 Product Specification.

For more information on RX testing with the **%XRFTEST** AT command, see RX test %XRFTEST in nRF91 AT Commands Reference Guide.

4.6.2 TX functionality test

The **%XRFTEST** TX test enables the RF transmitter with the given parameters. It also returns the internal measurement result of TX power. OFF <operation> disables the RF transmitter.

Using high TX power levels results in high current consumption. This should be considered in the power supply setup if several products are tested in parallel.

Note: Starting the **%XRFTEST** TX test with a high power level causes RF disturbance that may interfere with other cellular users. Using an RF shielded chamber for this kind of testing is recommended.

nRF9160 responds to the **%XRFTEST** TX test with the measured TX power at the antenna. The power level is given in the q4 (dB) format. Dividing the result by 2^4 = 16 gives the dB value of the antenna power.

The following command example executes a TX test:

```
%XRFTEST=1,1,5,8300,17,0,3,12,0,0,0,0,0 // TX ON (B5,830.0MHz,+17dBm, NB1,BPSK,12 tones,
 tone
start position 0, subcarrier spacing 15kHz, system BW NB1, NB index 0, TX burst mode
 disabled)
%XRFTEST: 271 // Result: 271/16 = 16.9dBm OK

%XRFTEST=1,0 // TX OFF OK
```

The TX functionality test input parameters are described in the following table:

Parameter name	Parameter description	Range	Value description
<param0>	3GPP band number	1–66	Bands supported by nRF9160
<param1>	Frequency 100 kHz raster	6000–22000	Corresponds to 600–2200 MHz
<param2>	TX signal power	+23 to –50	TX signal power at the antenna
<param3>	System mode	0–1	NB1 = 0 M1 = 1
<param4>	Modulation	CW– 16QAM	TX signal properties. Available options depend on the selected system mode.
<param5>	*Resource Block (RB)* or SC count	1–12	TX signal properties. Available options depend on the selected system mode.
<param6>	*RB* or SC start position	0–11	TX signal properties. Available options depend on the selected system mode.
<param7>	Subcarrier spacing	0–1	TX signal properties. Available options depend on the selected system mode.
<param8>	System bandwidth	0–4	TX signal properties. Available options depend on the selected system mode.
<param9>	Narrowband index	0–3	TX signal properties. Available options depend on the selected system mode.
<param10>	TX burst mode	0–1	TX signal properties. Enables non-continuous TX transmission.

Table 23: Input parameters of TX functionality test

For details on parameters supported by each modem firmware release, see nRF91 AT Commands Reference Guide.

For bands supported by nRF9160, see nRF9160 Product Specification.

For more information on TX testing with the **%XRFTEST** AT command, see TX test %XRFTEST in nRF91 AT Commands Reference Guide.

4.6.3 GPS functionality test

The **%XRFTEST** GPS SNR test starts *GPS SNR* measurement. By default, the test expects the *CW* in the signal generator to be at 1575.750 MHz, which means a 330 kHz offset from the *GPS* center frequency of 1575.42 MHz. The duration of the measurement is 1 ms.

The test is automatically disabled when it is finished. OFF <operation> is not needed due to automatic stop.

The recommended signal level for *GPS* testing is -90 dBm. The expected *SNR* with this signal level is normally more than 16 dB. For details on setting the correct signal level parameter for the **%XRFTEST** command, see GPS mode on page 18.

AFC correction can be performed to increase the accuracy of the *SNR* measurement. This can compensate the frequency error between nRF9160 and the test equipment used. AFC measurement and setting is supported by modem firmware v1.2.x and later.

> **Note:** The reported *SNR* is very sensitive to external RF disturbance that may be present in the test environment. An RF shielded chamber is recommended as a stable test environment. A known device, such as a golden unit, can be used as a reference to confirm the validity of the test result.

The following command example executes a *GPS SNR* test with AFC correction enabled, default receiver frequency, and external *LNA* gain of 16 dB:

```
%XRFTEST=2,1,-74,1
%XRFTEST: 361, -18758 // Result: SNR 361/16 = 22.56dB, RSSI -18758/256
= -73.3dBm OK
```

The *GPS* functionality test has one input parameter that is described in the following table:

Parameter name	Parameter description	Range	Value description
<param0>	Signal level at antenna	–127 to –25	Signal level at the nRF9160 antenna input (dBm)
<param1>	AFC correction	0–1	AFC correction control in measurement
<param2>	Frequency	1565.42–1585.42	Manual setting of RF frequency

Table 24: Input parameter of GPS functionality test

nRF9160 responds to the **%XRFTEST** GPS SNR test with the measured *GPS SNR* and RSSI values. The *SNR* is given in the q4 (dB) format. Dividing the result by 2^4 = 16 gives the dB value of the antenna power.

The RSSI signal level at the antenna is given in the q8 (dBm) format. Dividing the result by 2^8 =256 gives the dBm value of the RSSI.

> **Note:** The *GPS* signal level parameter in the **%XRFTEST** command refers to the signal level at the nRF9160 *GPS* antenna input pin. Consider external *LNA* gain with this setting.

For more information on *GPS* testing with the **%XRFTEST** AT command, see GPS SNR test %XRFTEST in nRF91 AT Commands Reference Guide.

4.6.4 RF antenna tests

A functionality test of the antenna should be part of the test flow in production. The antenna test method should be chosen according to the product configuration which determines the suitability of each test method.

When using external components on the nRF9160 antenna signal path, all functional modes should be included. For example, in the case of an antenna tuner, selecting enough RF test frequencies to cover all setting combinations achieves this.

4.6.4.1 Antenna presence DC test

nRF9160 supports testing antenna presence based on the *DC* current flow.

Antenna presence can be tested with the Nordic-proprietary **%XANTDETMAGPIO** AT command. The command reads the status of the MAGPIO pin and reports the detection based on the *DC* grounding of the antenna feed pin. The antenna is considered detected when the pin is grounded.

> **Note:** The hardware of the product needs to be correctly configured to enable the MAGPIO presence test. The MAGPIO line must be isolated from the RF signal with a coil, and a *DC* blocking capacitor must be placed towards the nRF9160 antenna input. For an example of the implementation, see nWP033 - nRF9160 Antenna and RF Interface Guidelines.

For more information on the **%XANTDETMAGPIO** AT command, see Antenna detection test %XANTDETMAGPIO in nRF91 AT Commands Reference Guide.

4.6.4.2 Radiated RF test

The most reliable antenna presence testing can be done with radiated RF coupler measurement. In the test, the measurement antenna is placed into a test fixture near the product antenna which creates a so-called near-field condition between the two antennas. The design of the coupler is always product specific and needs to be matched with the final product design.

This setup can be used to perform RX functionality test on page 38 and TX functionality test on page 39.

> **Note:** When setting targets and acceptance limits for the RF test, the fact that measurement accuracy is degraded compared to the conducted measurements should be considered.

> **Note:** Radiated RF tests should always be done inside an RF shielded chamber to avoid issues caused by external disturbance.

4.7 Finalizing production

After the product has passed all production tests, the firmware needs to be programmed for customer use and protection needs to be applied to the device.

4.7.1 Programming modem firmware

The nRF9160 modem is preprogrammed with a firmware that supports the AT commands functionality needed for recommended production testing. The version of the preprogrammed firmware can change over time. The firmware must be updated to a complete modem firmware that is product-certified. You can check the version of the preprogrammed modem firmware with the **%SHORTSWVER** AT command. For more information, see Short software identification %SHORTSWVER in nRF91 AT Commands Reference Guide. For available firmware releases, see nRF9160 Downloads.

For information on programming using a customized setup in production, see Updating the modem in nAN41 - nRF9160 Production Programming and nrfjprog executable or DLL in nRF Command Line Tools.

To update the modem firmware, connect nRF9160's *SWD* interface to a debugger. Commercially available programming units, such as SEGGER J-Link, can be used.

4.7.2 Updating GNSS almanac

The nRF9160 *GPS* receiver uses an almanac file to optimize satellite search and achieve location fix in a shorter period of time. The almanac file is preprogrammed, but it is recommended to be updated to the latest available version to ensure an optimal time for the first fix when *GPS* is activated in the end-product.

The **%XFILEWRITE** AT command can be used to update the almanac file. For more information on the **%XFILEWRITE** AT command, see Write content to file %XFILEWRITE in nRF91 AT Commands Reference Guide.

4.7.3 Modem settings

When the production test is complete, the Nordic-proprietary **%XPRODDONE** AT command can be run. After the command runs, nRF9160 rejects the programming of older firmware versions and versions with a smaller version number. AT command support for the RF test can also be disabled. For critical information, see Customer production done %XPRODDONE in nRF91 AT Commands Reference Guide.

nRF9160 supports the authentication of AT commands with the Nordic-proprietary **%XSUDO** AT command. For information on the use of the **%XSUDO** AT command and creating and storing provisioning keys, see Authenticated access %XSUDO in nRF91 AT Commands Reference Guide.

4.7.4 Application programming and settings

After the application firmware has been successfully programmed, mechanisms to protect the device can be activated.

Secure Access Port Protection (SECUREAPPROTECT) prevents the secure debugger from accessing the CPU and memories. This means that memory regions marked secure in the SPU and CPU while running secure code are inaccessible.

Access Port Protection (APPROTECT) prevents all debugger access to the CPU and memories. After enabling access port protection, only a full erase through the control access port (CTRL-AP) allows debugging or flash access. This can be done by performing a CTRL-AP erase all.

Erase Protection (ERASEPROTECT) prevents a CTRL-AP erase all from lifting the access port protection. When this feature is enabled, a debugger must first authenticate with the firmware through the CTRL-AP MAILBOX and ERASEPROTECT.DISABLE registers before a CTRL-AP erase all is possible.

For more information on settings to protect the device, see Enabling device protection in nAN41 - nRF9160 Production Programming and nRF9160 CTRL-AP - Control access port in nRF9160 Product Specification.

5 Appendix

The following options are needed on Rohde & Schwarz CMW500 for testing the *LTE-M* and *NB-IoT* modes.

LTE-M:

- KM500 – TX measurement LTE FDD
- KS500 – LTE FDD signaling
- KS510 – LTE Release 8, SISO, signaling or network emulation
- KS590 – LTE (eMTC) signaling or network emulation

NB-IoT:

- KM300 – NB-IoT TX measurement
- KS300 – NB-IoT signaling

The R&S®CMW100 WMT test solution supports nRF9160. For more information, contact Rohde & Schwarz.

Glossary

Access Port Protection (APPROTECT)

A register used to prevent read and write access to all CPU registers and memory-mapped addresses.

Carrier Wave (CW)

A single-frequency electromagnetic wave that can be modulated in amplitude, frequency, or phase to convey information.

Cat-M1

LTE-M User Equipment (UE) category with a single RX antenna, specified in 3GPP Release 13.

Cat-NB1

Narrowband Internet of Things (NB-IoT) User Equipment (UE) category with 200 kHz UE bandwidth and a single RX antenna, specified in 3GPP Release 13.

DC

Direct Current

Device Under Test (DUT)

A manufactured product undergoing testing.

Discontinuous Reception (DRX)

A method in mobile communication to conserve the battery of a mobile device by turning the RF modem in a sleep state.

Development Kit (DK)

A development platform used for application development.

Erase Protection (ERASEPROTECT)

A register used to block NVMC ERASEALL and CTRL-AP.ERASEALL functionality.

Extended Discontinuous Reception (eDRX)

A method to conserve the battery of an IoT (Internet of Things) device by allowing it to remain inactive for extended periods.

Global Positioning System (GPS)

A satellite-based radio navigation system that provides its users with accurate location and time information over the globe.

Integrated Circuit (IC)

A semiconductor chip consisting of fabricated transistors, resistors, and capacitors.

Low Mid High (LMH)

A measurement channel definition.

Low-Noise Amplifier (LNA)

In a radio receiving system, an electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio.

LTE-M

An open standard that is most suitable for medium throughput applications requiring low power, low latency, and/or mobility, like asset tracking, wearables, medical, POS, and home security applications. Also known as Cat-M1.

MIPI RF Front-End Control Interface (RFFE)

A dedicated control interface for the RF front-end subsystem. *MIPI Alliance*

Narrowband Internet of Things (NB-IoT)

A narrowband technology standard with longer range, lower throughput, and better penetration in, for example, cellars and parking garages compared to LTE-M. NB-IoT is most suitable for static, low throughput applications like smart metering, smart agriculture, and smart city applications. Also known as Cat-NB1.

Noise Factor (NF)

The relation of the *SNR* in the device input to the *SNR* in the device output.

Over-the-Air (OTA)

Refers to any type of wireless transmission.

Power Saving Mode (PSM)

A feature introduced in 3GPP Release 12 to improve battery life of IoT (Internet of Things) devices by minimizing energy consumption. The device stays dormant during the PSM window.

Printed Circuit Board (PCB)

A board that connects electronic components.

Production Test Image (PTI)

A modem firmware version used in the device manufacturing phase.

Reference Measurement Channel (RMC)

3GPP specified measurement channels for RF performance verification.

Resource Block (RB)

The smallest unit of resources that can be allocated to a user.

Right Hand Circular Polarization (RHCP)

Circular polarization in which the electric field vector rotates in a right-hand sense with respect to the direction of propagation.

Secure Access Port Protection (SECUREAPPROTECT)

A register used to prevent read and write access to all secure CPU registers and secure memory-mapped addresses.

Serial Wire Debug (SWD)

A standard two-wire interface for programming and debugging Arm CPUs.

Signal-to-Noise Ratio (SNR)

The level of signal power compared to the level of noise power, often expressed in decibels (dB).

Subscriber Identity Module (SIM)

A card used in *User Equipment (UE)* containing data for subscriber identification.

System in Package (SiP)

A number of integrated circuits, often from different technologies, enclosed in a single module that performs as a system or subsystem.

System on Chip (SoC)

A microchip that integrates all the necessary electronic circuits and components of a computer or other electronic systems on a single integrated circuit.

Tracking Area Update (TAU)

A procedure initiated by the *UE* when moving to a new tracking area in the LTE (Long-term Evolution) system.

Universal Asynchronous Receiver/Transmitter (UART)

A hardware device for asynchronous serial communication between devices.

Universal Integrated Circuit Card (UICC)

A new generation *SIM* used in *UE* for ensuring the integrity and security of personal data.

Universal Serial Bus (USB)

An industry standard that establishes specifications for cables and connectors and protocols for connection, communication, and power supply between computers, peripheral devices, and other computers.

Unique Slave Identifier (USID)

A unique address for identifying each slave device in an RFFE (RF Front-End) system.

User Equipment (UE)

Any device used by an end-user to communicate. The UE consists of the Mobile Equipment (ME) and the Universal Integrated Circuit Card (UICC).

Acronyms and abbreviations

These acronyms and abbreviations are used in this document.

APPROTECT
: Access Port Protection

Cat-M1

Cat-NB1

CW
: Carrier Wave

DC
: Direct Current

DK
: Development Kit

DRX
: Discontinuous Reception

DUT
: Device Under Test

eDRX
: Extended Discontinuous Reception

ERASEPROTECT
: Erase Protection

GPS
: Global Positioning System

IC
: Integrated Circuit

LMH
: Low Mid High

LNA
: Low-Noise Amplifier

MIPI RFFE
: MIPI RF Front-End Control Interface

NB-IoT
: Narrowband Internet of Things

NF
: Noise Factor

OTA
: Over-the-Air

PCB
Printed Circuit Board

PSM
Power Saving Mode

PTI
Production Test Image

RB
Resource Block

RHCP
Right Hand Circular Polarization

RMC
Reference Measurement Channel

SECUREAPPROTECT
Secure Access Port Protection

SIM
Subscriber Identity Module

SiP
System in Package

SNR
Signal-to-Noise Ratio

SoC
System on Chip

SWD
Serial Wire Debug

TAU
Tracking Area Update

UART
Universal Asynchronous Receiver/Transmitter

UICC
Universal Integrated Circuit Card

USB
Universal Serial Bus

USIM
Unique Slave Identifier

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