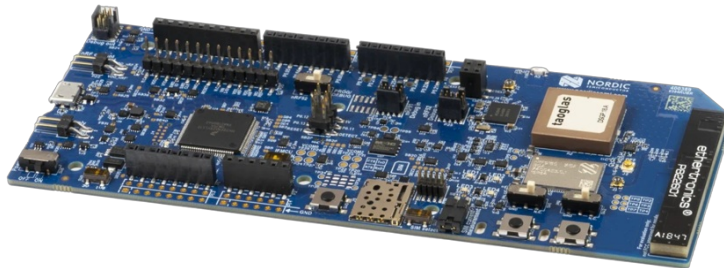


NORDIC SEMICONDUCTOR nRF9160 Hardware Integration User Guide

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About this document

This document complements the nRF9160 Product Specification to provide recommendations and guidelines for designing devices based on the nRF9160 module. This document is intended for the customers of Nordic Semiconductor, especially device manufacturers and hardware engineers.

Device overview

nRF9160 is an LTE made simple cellular IoT System in Package (SiP) module that is pre-certified for customers for building end devices on it. nRF9160 consists of an Arm® Cortex® – M33 microcontroller and 3GPP LTE release 13 compliant embedded Cat-M and Cat-NB LTE modem. The microcontroller has an inbuilt 1 MB flash memory, Arm TrustZone® , and 32 general purpose I/O pins.

The LTE modem includes transceiver with global cellular band coverage, ultra-low current consumption, and single 50 Ω antenna interface.

Operating conditions

For the nRF9160 temperature range, voltage range, and physical dimensions, see nRF9160 Product Specification.

Bands of operation

For an up-to-date list of certified cellular bands, see section Regulatory certifications on the Nordic Semiconductor web page.

Supported FCC rules

The nRF9160 module has been certified to comply with the following FCC rules:

- 47 CFR Part 22
- 47 CFR Part 24
- 47 CFR Part 27
- 47 CFR Part 90
- 47 CFR part 2.1091
- FCC Part 15 Subpart B

If the device manufacturer will apply the integration and test instructions of this document to the host device, then these certifications can be applied to the host device, except for FCC Part 15 Subpart B which needs to be retested. For more information, see nWP033 – nRF9160 Antenna and RF Interface Guidelines and nWP034 – nRF9160 Hardware Verification Guidelines.

The host manufacturer can use nRF9160's FCC ID if the device meets the conditions of the FCC certificate. Normally, the conditions are the following:

- A minimum of 20 cm distance from the human body.
- No colocation with other transmitters. Typically, this condition needs to be reviewed by the FCC lab.
- Antenna gain below the requirements.

Host device manufacturer responsibility

Note: The nRF9160 device is only authorized for the rules listed in Supported FCC rules. The host device manufacturer is responsible for compliance to any other FCC rules that apply to the host device not covered by the nRF9160 grant of certification. It is mandatory for the host device manufacturer to assure the final device's compliance with FCC Part 15 Subpart B even if certification has been granted to nRF9160.

nRF9160 module

The nRF9160 SiP module consists of the nRF9160 System on Chip (SoC), power management and RF frontend section, and passive and clocking components. External to the module are supply source (battery or mains), SIM solution, and any customer peripherals and sensors. For further details of blocks and their software controls and dependencies, see nRF9160 Product Specification.

Block diagram

The following block diagram illustrates the nRF9160 SiP module.

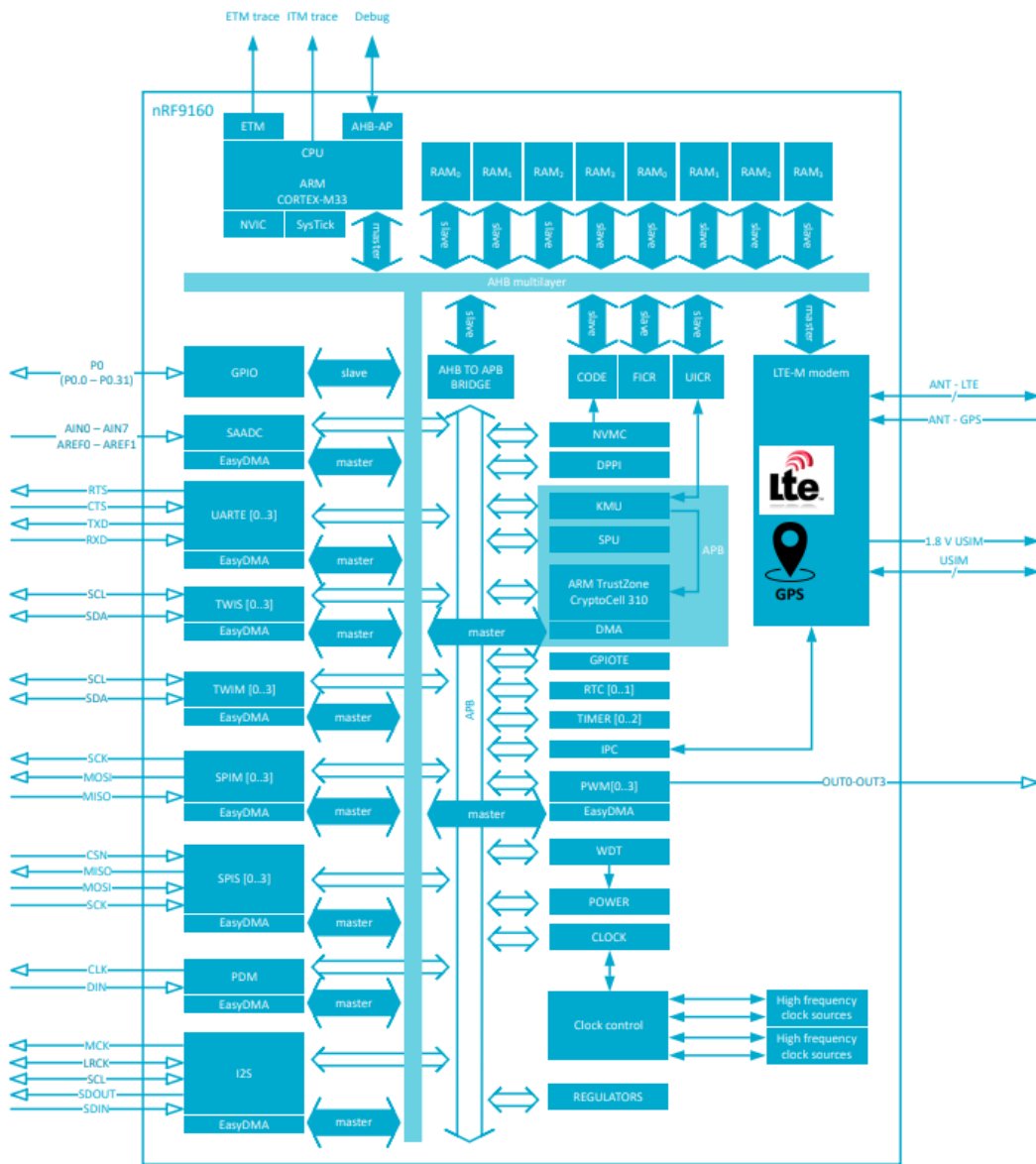


Figure 1: nRF9160 module block diagram

Pin assignment

The following figure illustrates the nRF9160 pinout. For more information, see Pin assignments in nRF9160 Product Specification.

10	Reserved		Can be used to improve mechanical rigidity. Solder to main board but do not connect electrically.
11	GND_Shield	Power	Microshield GND, connect strongly to module GND
12	VDD_GPIO	Power	GPIO power supply input and logic level for GPIOs
13	DEC0	Power	Module internal power supply decoupling option.
14	GND_Shield	Power	Microshield GND, connect strongly to module GND
15	P0.08	GPIO	Digital I/O, VDD_GPIO level
16	P0.09	GPIO	Digital I/O, VDD_GPIO level
17	GND_Shield	Power	Microshield GND, connect strongly to module GND
18	P0.10	GPIO	Digital I/O, VDD_GPIO level
19	P0.11	GPIO	Digital I/O, VDD_GPIO level
20	P0.12	GPIO	Digital I/O, VDD_GPIO level
21	GND_Shield	Power	Microshield GND, connect strongly to module GND
22	VDD2	Power	RFFE power supply input. Tie to the same voltage level as VDD1.

23	P0.13	GPIO	Digital I/O and analog input, VDD_GPIO level
24	P0.14	GPIO	Digital I/O and analog input, VDD_GPIO level
25	P0.15	GPIO	Digital I/O and analog input, VDD_GPIO level
26	P0.16	GPIO	Digital I/O and analog input, VDD_GPIO level
27	GND_Shield	Power	Microshield GND, connect strongly to module GND
28	P0.17	GPIO	Digital I/O and analog input, VDD_GPIO level
29	P0.18	GPIO	Digital I/O and analog input, VDD_GPIO level
30	P0.19	GPIO	Digital I/O and analog input, VDD_GPIO level
31	GND_Shield	Power	Microshield GND, connect strongly to module GND
32	nRESET	System reset	SoC reset pin
33	SWDCLK	SWD	Serial wire debug & programming clock input
34	SWDIO	SWD	Serial wire debug & programming interface
35	P0.20	GPIO	Digital I/O and analog input, VDD_GPIO level
36	GND_Shield	Power	Microshield GND, connect strongly to module GND

37	P0.21	GPIO	Digital I/O and trace buffer clock, VDD_GPIO level
38	P0.22	GPIO	Digital I/O and trace buffer TRACEDATA[0], VDD_GPIO level
39	P0.23	GPIO	Digital I/O and analog input TRACEDATA[1], VDD_GPIO level
40	P0.24	GPIO	Digital I/O and analog input TRACEDATA[2], VDD_GPIO level
41	GND_Shield	Power	Microshield GND, connect strongly to module GND
42	P0.25	GPIO	Digital I/O and analog input TRACEDATA[3], VDD_GPIO level
43	SIM_RST	SIM	SIM reset
44	GND_Shield	Power	Microshield GND, connect strongly to module GND
45	SIM_DET	SIM	SIM detect
46	SIM_CLK	SIM	SIM clock
47	GND_Shield	Power	Microshield GND, connect strongly to module GND
48	SIM_IO	SIM	SIM data
49	SIM_1V8	SIM	1.8V power supply output for SIM
50	GND_Shield	Power	Microshield GND, connect strongly to module GND

51	Reserved	Reserved	Can be used to improve mechanical rigidity. Solder to main board but do not connect electrically.
52	GND_Shield	Power	Microshield GND, connect strongly to module GND
53	MAGPIO2	GPIO	Digital I/O, controllable by APP and MDM, fixed 1.8V
54	MAGPIO1	GPIO	Digital I/O, controllable by APP and MDM, fixed 1.8V
55	MAGPIO0	GPIO	Digital I/O, controllable by APP and MDM, fixed 1.8V
56	GND_Shield	Power	Microshield GND, connect strongly to module GND
57	VIO	RF FE ctrl	Digital I/O, MIPI RF FE VIO compatible, fixed 1.8V
58	SCLK	RF FE ctrl	Digital I/O, MIPI RF FE CLK compatible, fixed 1.8V
59	SDATA	RF FE ctrl	Digital I/O, MIPI RF FE DATA compatible, fixed 1.8V
60	GND_Shield	Power	Microshield GND, connect strongly to module GND
61	ANT	RF	Single end 50Ω LTE antenna port
62	GND_Shield	Power	Microshield GND, connect strongly to module GND
63	GND_Shield	Power	Microshield GND, connect strongly to module GND

64	AUX	RF	Single end 50Ω ANT loop-back port, external matching network recommended.
65	GND_Shield	Power	Microshield GND, connect strongly to module GND
66	GND_Shield	Power	Microshield GND, connect strongly to module GND
67	GPS	RF	Single end 50Ω GPS input port
68	GND_Shield	Power	Microshield GND, connect strongly to module GND
69	GND_Shield	Power	Microshield GND, connect strongly to module GND
70	Reserved	Reserved	Can be used to improve mechanical rigidity. Solder to main board but do not connect electrically.
71	Reserved	Reserved	Can be used to improve mechanical rigidity. Solder to main board but do not connect electrically.
72	GND_Shield	Power	Microshield GND, connect strongly to module GND
73	Reserved	Reserved	Can be used to improve mechanical rigidity. Solder to main board but do not connect electrically.
74-82	GND_Shield	Power	Microshield GND, connect strongly to module GND
83	P0.26	GPIO	Digital I/O, VDD_GPIO level
84	P0.27	GPIO	Digital I/O, VDD_GPIO level

85	GND_Shield	Power	Microshield GND, connect strongly to module GND
86	P0.28	GPIO	Digital I/O, VDD_GPIO level
87	P0.29	GPIO	Digital I/O, VDD_GPIO level
88	P0.30	GPIO	Digital I/O, VDD_GPIO level
89	P0.31	GPIO	Digital I/O, VDD_GPIO level
90	GND_Shield	Power	Microshield GND, connect strongly to module GND
91	COEX2	GPIO	Coexistence interface, VDD_GPIO level
92	COEX1	GPIO	Coexistence interface, VDD_GPIO level
93	COEX0	GPIO	Coexistence interface, VDD_GPIO level
94	GND_Shield	Power	Microshield GND, connect strongly to module GND
95	P0.00	GPIO	Digital I/O, VDD_GPIO level
96	P0.01	GPIO	Digital I/O, VDD_GPIO level
97	P0.02	GPIO	Digital I/O, VDD_GPIO level
98	GND_Shield	Power	Microshield GND, connect strongly to module GND

99	P0.03	GPIO	Digital I/O, VDD_GPIO level
100	P0.04	GPIO	Digital I/O, VDD_GPIO level
101	ENABLE	Power	Module enable signal. Connect to VDD1 to enable module.
102	VDD1	Power	SoC power supply input. Must be at same voltage level as VDD2 power supply input for RFFE.
103	VSS	Power	Module main GND, connect strongly to application board GND plane. Main thermal exit path from module to application board.
104-127	Reserved		Can be used as improvement of mechanical rigidity. Solder to main board but do not connect electrically.

Table 1: Pin assignments

Antennas

The nRF9160 module supports multiple cellular frequency bands as listed in Bands of operation. As the electrical size of the antenna sets fundamental limits for antenna bandwidth, it is recommended to select an antenna supporting only the operational bands of the final device and optimize the antenna performance at frequencies in question. The smaller the electrical size, the narrower the reachable bandwidth and the lower the radiation efficiency.

If wide bandwidth and small physical size is required from the final device, antenna tuners may be advantageous: antenna input matching can be optimized for the frequency of operation at a time. It is also possible to design the antenna to have tunable resonant frequency. Antenna suppliers and design houses provide solutions for size limited antennas. The nRF9160 module provides control for external antenna tuners. For more information, see nWP033 – nRF9160 Antenna and RF Interface Guidelines.

Note: The nRF9160 module has been certified only with the antenna solution presented in Reference circuitry on page 17. However, it is possible to use other antenna types and models with nRF9160. Adequate testing and regulator certifications are always required from the final device regardless of antenna selection.

Antenna interface

The nRF9160 module has a single-ended 50 Ω antenna port where the antenna solution shall be connected. nRF9160 is evaluated with a 50 Ω antenna load. To ensure good overall RF performance, antenna impedance and the characteristic impedance of the transmission line (i.e. cable) connecting the antenna and antenna port must be 50 Ω . Impedance mismatch may lead to performance degradation. Maximum antenna VSWR 2:1 is

recommended but VSWR 3:1 can still be accepted in the final device. Respective minimum return loss values are 9.5 dB and 6.0 dB.

The length of the transmission line from the antenna to the nRF9160 antenna port should be kept as short as possible to minimize losses, as this loss is directly deteriorating the module's transmitted and received power. Additionally, low-loss matching circuit between the antenna and the nRF9160 antenna port is recommended to minimize loss caused by antenna and PCB routing mismatch. Reserving space from device manufacturer's application board for matching components (e.g. π -circuit) is recommended.

This is because, for example, catalog antennas are typically tuned on reference board and differences to device mechanics may impact antenna impedance. It is also possible that device mechanics change during the development phase of the final device, and these modifications may impact antenna performance. Matching components can be used to compensate the impact of mechanics change to antenna impedance, and thus it may not be mandatory to modify the antenna itself.

The nRF9160 module has an internal ESD circuit in the antenna port, but additional ESD components at device manufacturer's application board may be used. The design of the ESD circuit shall be such that the impact on RF frequencies is negligible.

Note: ESD filtering may be necessary for some active components that can be used at antenna path. Such components can be, for example, RF switches and antenna tuners. For further ESD requirements, see the RF switch and antenna tuner datasheets.

Antenna port test connector

To run conductive RF tests, a test connector nearby the nRF9160 antenna port in the RF transmission line is needed. The 50 Ω impedance requirement applies also to the test connector, and VSWR and insertion loss should be minimal. Regardless of whether the nRF9160 antenna port is connected to an actual antenna or test equipment, the load at the nRF9160 antenna should remain as close to 50 Ω as possible.

For a test connector, microwave coaxial switch connectors (for example, Murata MM8130-2600) are a good choice for this purpose. For conductive tests, a test cable is plugged in which connects the nRF9160 antenna port to the test equipment instead of the antenna. When the test cable is plugged off, the nRF9160 antenna port is connected to the antenna for real use case or radiated testing. The layout for the connector must be carefully designed to fulfil the 50 Ω requirement. For detailed guidance on this, see the coaxial switch connectors datasheets.

Test modes

The nRF9160 module is fully calibrated and does not require any calibration in the device manufacturer's production. Instead, the manufacturer test should focus on the successful assembly of the module and the correct co-functionality of the peripheral components connected to nRF9160.

Device manufacturer testing should focus on items such as the following:

- Module is not damaged during handling and assembly
- All module pins are successfully soldered (connectivity and no shorts)
- Module functionality in final product
- Communication to module MCU
- All interfaces between the module and the peripheral circuits
- RF performance and antenna connection

The primary method to implement these tests is by programming FW on the application MCU that will control the chip during the test. The application MCU programming interface is defined in nRF9160 Product Specification. However, it is also possible to control the device through nRF9160 serial interface by AT commands. It requires flashing appropriate firmware in the nRF9160 exposing AT command API into physical interface. By this method nRF9160 can also be controlled not only in device production phase but also in device manufacturer development phase. For more information, see nWP034 – nRF9160 Hardware Verification Guidelines.

Note: For more information about RF performance related test modes and other supported test capabilities, see nRF91 AT Commands Reference Guide.

BB functional test

The nRF9160 programming interface can be used to test the digital interfaces. All GPIO and application MCU peripherals are described in nRF9160 Product Specification and LTE modem related IO interfaces (MAGPIO, MIPI RFFE, SIM) are accessed through AT commands described in nRF91 AT Commands Reference Guide.

RF functional test

In this document, the focus is on RF test modes and methods.

Device testing can be done either as radiated measurement or as conducted test if the device has a RF test connector. In both cases the test can be done with basic RF measurement equipment using the AT test commands that set up the module to test modes bypassing the LTE signaling protocol.

The nRF9160 transceiver supports three main test modes for RF performance verification: RX, TX, and GPS SNR test modes. A high level description of each test mode is given in the following sections.

Note: To avoid module damage during testing the nRF9160 antenna port must be terminated to either suitable antenna or 50 Ω termination.

Note: Since the AT test commands enable to emit RF power bypassing the LTE signaling protocol the emission can cause interference. This feature is thus only intended for use in controlled test environments and shall not be used during normal module operation following the instructions in Nordic Semiconductor documentation.

RX test:

RX ON command enables the RF receiver with the given parameters. It also measures antenna power with a time domain power meter and returns the measurement result. RX OFF command disables RF receiver.

RX ON has a total of four input parameters:

Parameter	Range	Description
3GPP band number	1 to 66	nRF9160 supported bands
Frequency 100 kHz raster	6000 to 22000	Corresponds to 600 to 2200 MHz
System mode	0 to 1	NB1 = 0, M1 = 1
Signal level at antenna	-127 to -25	Signal generator level at antenna [dBm]

Table 2: RX ON input parameters

The response to the test is RX signal power at antenna port measured by DUT given in q8 format. q8 format results can be converted into dBm value by dividing the result by 2^8 (= 256).

The example command enables the RF receiver for Band 1, 2140.0 MHz, -65 dBm, NB1 mode:

```
%XRFTTEST=0,1,1,21400,-65,0
%XRFTTEST: -17002
OK
```

Note: -17002/256 = -66.4 dBm

Figure 5: Example command

Test setup

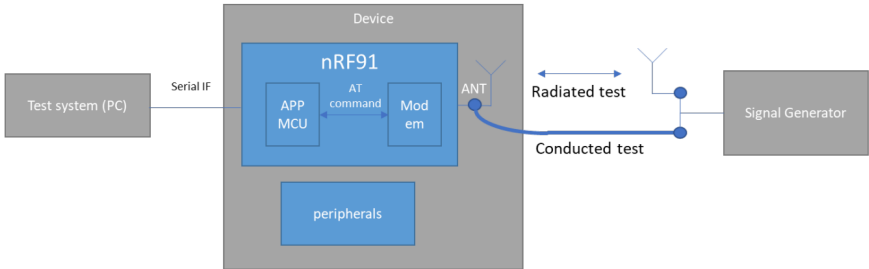


Figure 6: TX test setup example

GPS SNR test

GPS SNR ON command executes a GPS SNR test. GPS L1 frequency is 1575.42 MHz and this test expects the CW in signal generator to be 1575.750 MHz, i.e. 330 kHz offset from the center frequency. The measurement duration is 1 ms.

The test is disabled automatically after 1 ms and dedicated GPS SNR OFF command is not needed. GPS SNR ON has a one input parameter:

Parameter	Range	Description
Signal level at antenna	-127 to -25	Signal generator level at antenna [dBm]

Table 4: GPS SNR ON input parameters

The response to the test is GPS SNR value measured by DUT in q4 format. q4 format results can be converted into dB value by dividing the result by 2^4 (= 16).

Test setup

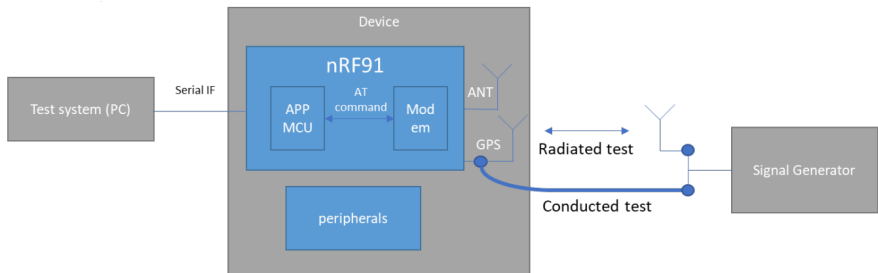


Figure 7: GPS SNR test setup example

RF signaling test

If full functionality against LTE network is tested in device manufacturing, it is possible to set up a signaling mode test either by live network test or by using a telecommunication tester.

The use of test equipment with LTE signaling capability is strongly recommended. If live network is used a network with good coverage and known signal quality is needed. Typically, it is difficult to guarantee live network quality over time and caution is needed in the interpretation of results. Live network signaling mode test is done by setting up a data connection and checking RX signal quality through AT command.

Reference circuitry

To ensure good RF performance when designing PCBs, it is highly recommended to use the PCB layouts and component values provided by Nordic Semiconductor. Documentation for the different package reference circuits, including Altium Designer files, PCB layout files, and PCB production files can be downloaded from www.nordicsemi.com.

Note: In this context reference circuitry illustrates the vehicle (i.e. nRF9160 Development Kit) applicable for the nRF9160 module granted the FCC certifications listed in Supported FCC rules on page 5. The given reference circuitry is a valid generic example of an nRF9160 based final device but does not limit the use of nRF9160 in any way.

Schematics

The following figure illustrates the reference schematics of nRF9160 Development Kit.

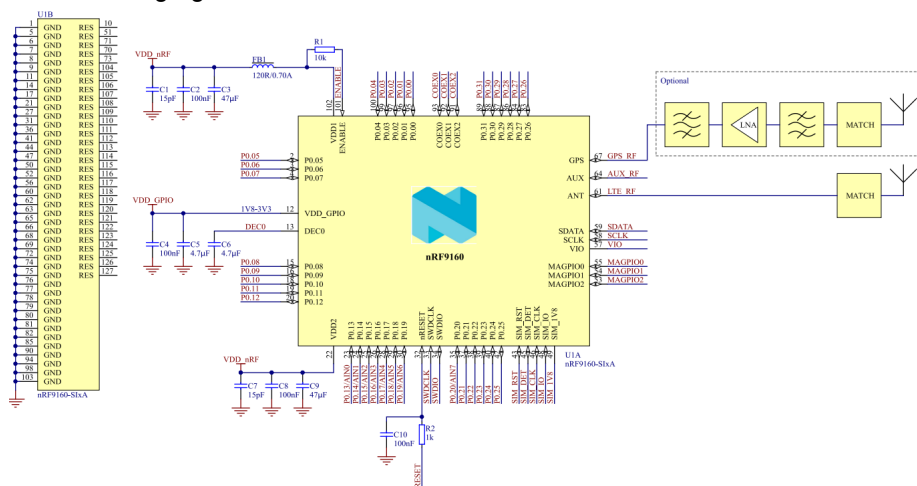


Figure 8: nRF9160 reference schematics

PCB layout

The PCB layout shown in **Figure 9: nRF9160 reference layout, metal layer 1** and **Figure 10: nRF9160 reference layout, metal layer 2** are part of the nRF9160 Development Kit reference layout. The figures show the PCB design details of the area where the cellular antenna is located.

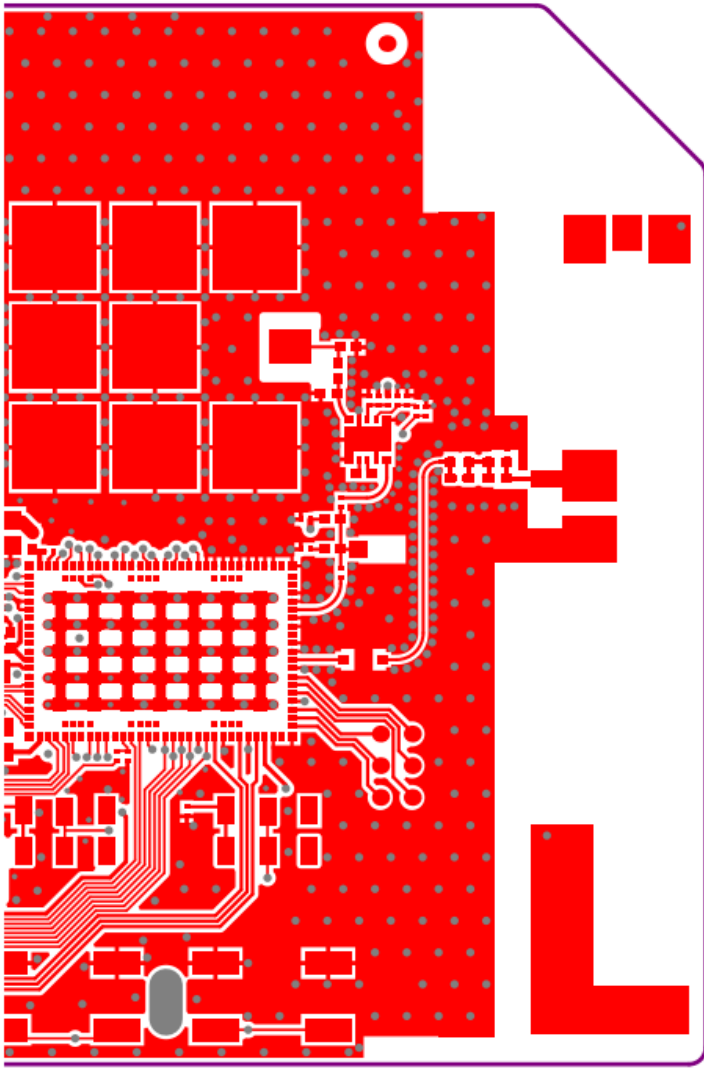


Figure 9: nRF9160 reference layout, metal layer 1 (top)

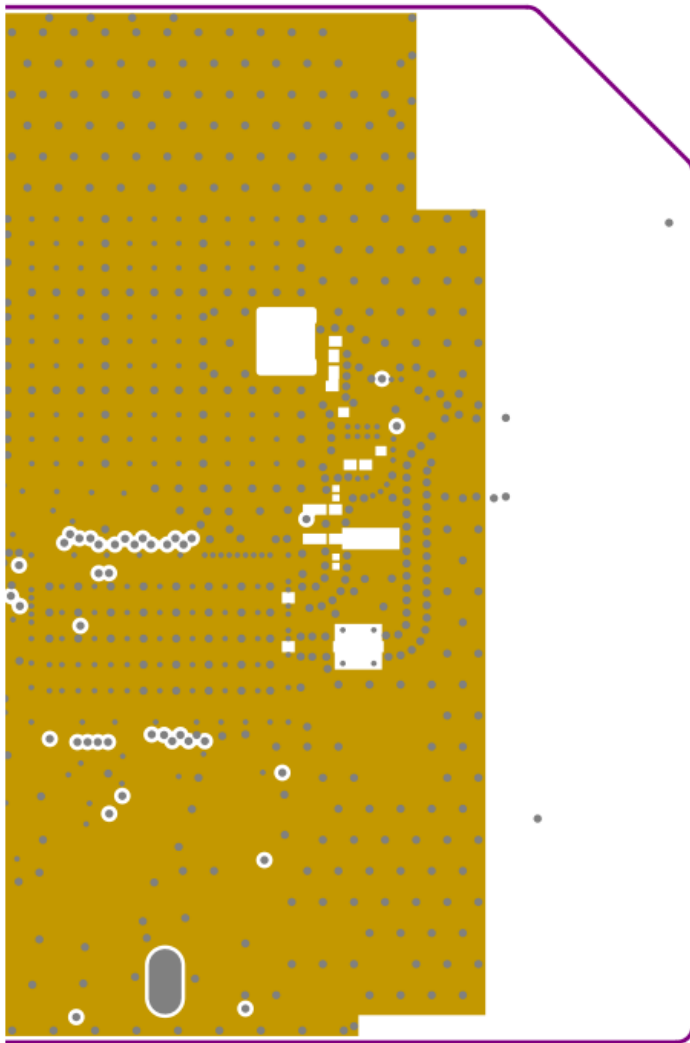


Figure 10: nRF9160 reference layout, metal layer 2

PCB specification

The nRF9160 Development Kit PCB stack-up and layer materials are shown in the following figure:

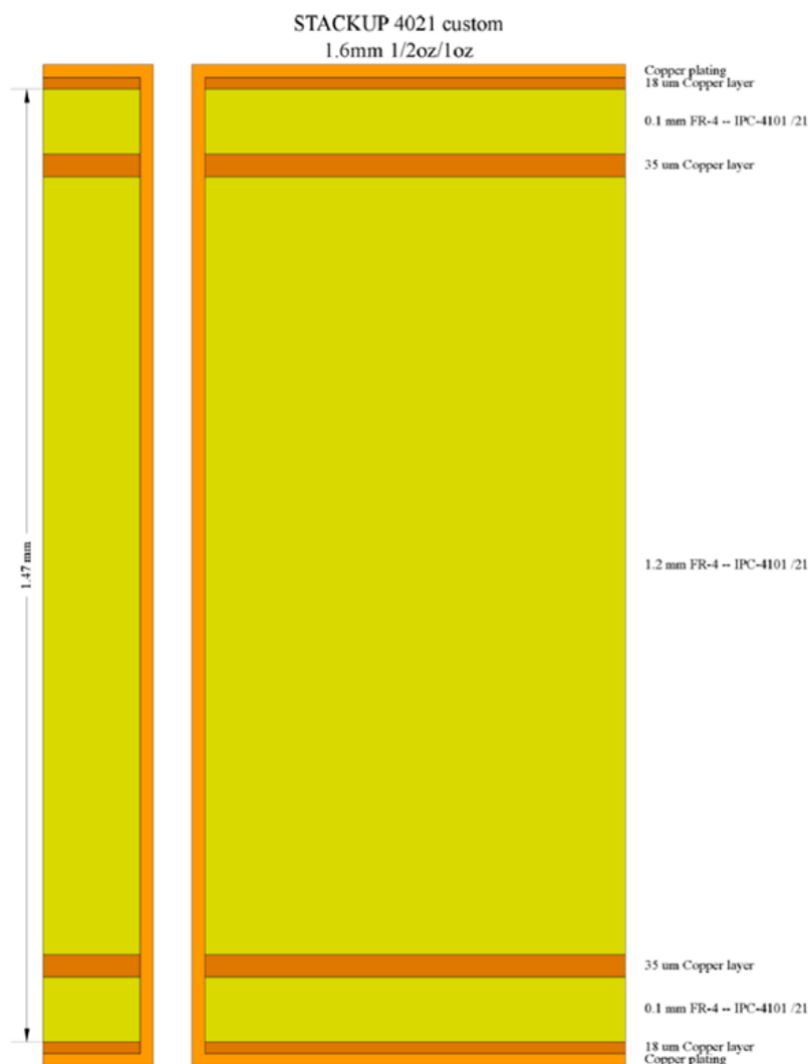


Figure 11: nRF9160 reference PCB (Elprint's 4-layer 4001 stack-up)

Antenna type

The antenna used in nRF9160 Development Kit is Ethertronics P822601 shown in the following figure. The antenna is a universal broadband FR4 embedded LTE antenna generally suitable for various cellular applications. Ethertronics' Universal Broadband Embedded LTE/LPWA antenna utilizes Isolated Magnetic Dipole™ (IMD) technology. For further details on the antenna, see the antenna supplier datasheet.



Figure 12: nRF9160 Development Kit antenna

Regulatory information

This section contains information on certified bands and FCC/ISED regulatory notices for nRF9160.

Certified bands

The following table shows the FCC and ISED certified LTE-M1 bands for nRF9160.

Band	FCC certification	ISED certification
Band 2	Yes	Yes
Band 4	Yes	Yes
Band 5	Yes	Yes
Band 12	Yes	Yes
Band 13	Yes	Yes
Band 14	Yes	No
Band 17	Yes	Yes
Band 25	Yes	Yes
Band 26	Yes	No
Band 66	Yes	Yes

Table 5: FCC and ISED certified LTE-M1 bands

The following table shows the FCC and ISED certified LTE-NB1 bands for nRF9160.

Band	FCC certification	ISED certification
Band 2	Yes	Yes
Band 4	Yes	Yes
Band 5	Yes	Yes
Band 12	Yes	Yes
Band 13	Yes	Yes
Band 17	Yes	Yes
Band 25	Yes	Yes
Band 26	Yes	No
Band 66	Yes	Yes

Table 6: FCC and ISED certified LTE-NB1 bands

For more information about the certified bands and the status of the ongoing certifications, see nRF9160 certifications.

FCC/ISED regulatory notices

FCC/ISED regulatory notices cover modification and interference statements, wireless and FCC Class B digital device notices, permitted antennas and labeling requirements.

Modification statement

Nordic Semiconductor has not approved any changes or modifications to this device by the user. Any changes or modifications could void the user's authority to operate the equipment.

Interference statement

This device complies with Part 15 of the FCC Rules and Industry Canada's licence-exempt RSS standards.

Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Wireless notice

This equipment complies with FCC and ISED radiation exposure limits set forth for an uncontrolled environment. The antenna should be installed and operated with minimum distance of 20 cm between the radiator and your body. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

Permitted antenna

This radio transmitter has been approved by FCC and ISED to operate with the antenna types listed below with the maximum permissible gain indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Band	Max gain
Band 2	9.0 dBi
Band 4	6.0 dBi
Band 5	7.1 dBi
Band 12	6.6 dBi
Band 13	6.9 dBi
Band 14	6.9 dBi
Band 17	6.6 dBi
Band 25	9.0 dBi
Band 26	7.0 dBi
Band 66	6.0 dBi

FCC Class B digital device notice

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

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

CAN ICES-3 (B)/NMB-3 (B)

This Class B digital apparatus complies with Canadian ICES-003.

Labeling requirements for the host device

The host device shall be properly labelled to identify the modules within the host device. The certification label of the module shall be clearly visible at all times when installed in the host device, otherwise the host device must be labelled to display the FCC ID and IC of the module, preceded by the words “Contains transmitter module”, or the word “Contains”, or similar wording expressing the same meaning, as follows:

Contains FCC ID: 2ANPO00NRF9160

Contains IC: 24529-NRF9160

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Documents / Resources

	<p>NORDIC SEMICONDUCTOR nRF9160 Hardware Integration [pdf] User Guide 00NRF9160, 2ANPO00NRF9160, nRF9160, Hardware Integration, nRF9160 Hardware Integration, Integration</p>
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References

-  [Nordic Semiconductor | Empowering Wireless Innovation - nordicsemi.com](http://www.nordicsemi.com)