nRF9160 Antenna and RF Interface Guidelines

nWP-033

White Paper

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Contents

Revision history

Date	Version	Description
October 2019	1.0	First release

1 Introduction

This document provides guidance for the integration of the nRF9160 LTE and *Global Positioning System (GPS)* RF interface and IoT device antenna.

The document outlines the basic antenna parameters and design factors impacting the antenna and the complete RF performance of the device and provides recommendations and requirements for the antenna to reach optimal RF performance with nRF9160. It offers examples of RF interface implementations including different test features and active RF components controlled by nRF9160 and an overview of RF and antenna test items to prepare for when building an IoT device containing nRF9160.

> **Note:** This document does not replace any antenna datasheet or document provided by antenna manufacturers. In antenna design related matters, antenna vendors and design houses should be consulted.

2 Antenna requirements

Antenna requirements for an IoT device using nRF9160 are summarized in the following table. The listed requirements apply to all frequencies supported by the IoT device.

Parameter	Requirement	Note
50 Ω impedance, antenna Voltage Standing Wave Ratio (VSWR)	<2:1	Recommendation
	<3:1	Absolute requirement
50 Ω impedance, antenna *Return Loss (RL)*	>9.5 dB	Recommendation
	>6.0 dB	Absolute requirement
Efficiency	>50%	Recommendation. Operators may have other efficiency requirements.
Maximum gain	[1]	
Maximum input power	1 W	

Table 1: Antenna requirements

2.1 Band support

nRF9160 supports multiple LTE frequency bands that are listed in nRF9160 certifications on the Nordic Semiconductor web page.

As the electrical size of the antenna sets limits to the antenna bandwidth, it is recommended to select an antenna that supports only the operational bands of the device and then optimize the antenna performance for the used frequencies. An antenna with smaller electrical size has a narrower reachable bandwidth and lower radiation efficiency. If wide bandwidth and small physical size are required from the device, antenna tuners may be beneficial, because antenna input matching can be optimized for the frequency of operation at a given time. The antenna can also be designed to have tunable resonant frequency. Antenna suppliers and design houses provide solutions for size-limited antennas. nRF9160 provides control for external antenna tuners. For more information, see External RF control on page 18.

2.2 Antenna interface

nRF9160 has one Single-Ended (SE) 50 Ω antenna interface (ANT) for all supported bands. nRF9160 is evaluated with a 50 Ω antenna load.

To ensure good performance, antenna impedance and the characteristic impedance of the transmission line connecting the antenna to the ANT pin must be 50 Ω. Impedance mismatch leads to performance deterioration.

For the antenna, a maximum of VSWR 2:1 is preferred, but VSWR 3:1 is acceptable. The return loss value in VSWR 2:1 is 9.5 dB, and in VSWR 3:1 it is 6.0 dB. The length of the transmission line from the antenna to ANT pin should be kept as short as possible to minimize losses, as loss deteriorates the module's

[1] See Regulatory Certificates at nRF9160 certifications.

transmitted and received power and leads to drawbacks in power consumption and coverage. A maximum of 0.5 dB transmission line loss should be targeted.

To minimize impedance mismatch, it is recommended to use a low-loss matching circuit that uses *High-Q* and tight tolerance components next to the antenna. Catalog antennas are tuned on the antenna vendors' reference boards. The differences between the antenna vendor reference boards and device mechanics may impact antenna impedance. For example, device mechanics may change in the development phase, and these modifications may impact antenna impedance. Matching components can be used to compensate the impact of device mechanics, for example, casing, *Printed Circuit Board (PCB)*, or battery, on the antenna impedance.

nRF9160 includes an Electrostatic Discharge (ESD) circuit on the ANT pin, but additional ESD components may be used if the impact on RF frequencies is negligible. ESD filtering may be necessary for some active components, such as switches or antenna tuners, in the antenna path. For the ESD requirements, see the component datasheets. The ANT pin is *DC* grounded.

> **Note:** The nRF9160 *System in Package (SiP)*'s internal ESD protection is intended for 1.5 kV Human Body Model (HBM) level.

To run conductive RF tests, a test connector or cable is needed. The connector or cable is recommended to be located as close as possible to the ANT pin. For more information on RF testing, see Antenna and RF test on page 20. Antenna detection can be used in device production or when debugging the device. For more information, see Antenna tests on page 21.

2.2.1 Antenna interface example

The example in Figure 1: Antenna interface example on page 6 has a three-component circuit reservation for the antenna matching circuit. Depending on the *PCB* stack-up and the size of the selected components, removing ground under the antenna interface component pads on the *PCB* may be needed.

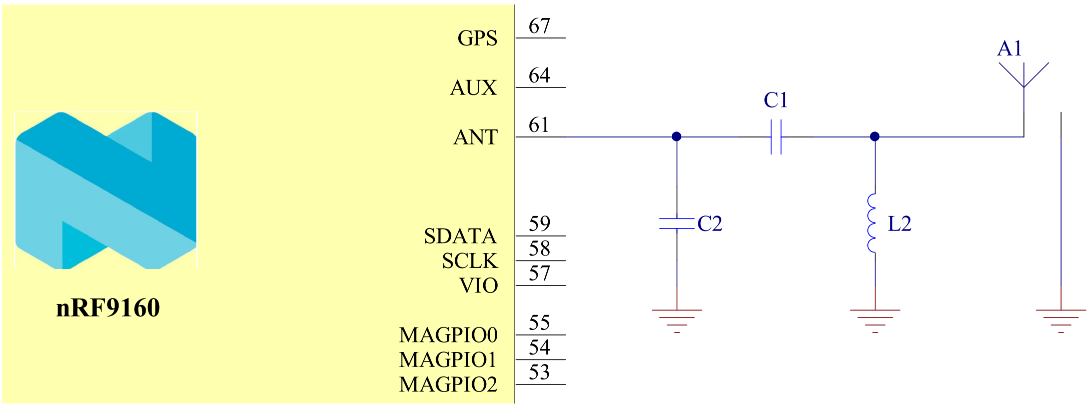

Figure 1: Antenna interface example

Reference	Description
A1	Antenna
L2	Antenna matching component
C1	
C2	

Table 2: Components of antenna interface example

The following components are highlighted in Figure 2: Layout of antenna interface example on page 7:

1. Antenna matching circuit
2. Antenna keep-out area

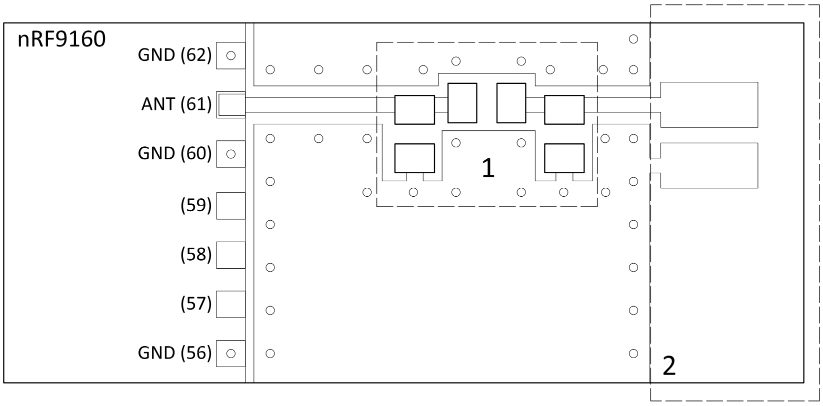

Figure 2: Layout of antenna interface example

2.3 Antenna radiation parameters

Antenna efficiency is a measure of radiated power relative to total antenna power including losses. nRF9160 does not set requirements to antenna radiation parameters, but antenna efficiency is an important parameter in low power devices as it directly impacts the radiated and received power and thus current consumption and coverage.

An omnidirectional antenna and a relatively low peak gain is the most desirable solution for an IoT device as a terminal device's orientation will usually vary.

Network operators may require *Over-the-Air (OTA)* testing of the device (see Conductive tests on page 20) and may have specific antenna efficiency requirements or requirements for the parameters that are related to the efficiency of different device categories.

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. For more information, see Antenna tests on page 21.

3 Antenna design considerations

Once the operational frequency bands and device concept are known, the antenna selection process or custom antenna design work can start.

Deciding between using an external or internal, also known as integrated, antenna is one of the first choices that needs to be made. As an external antenna is not as size limited as an internal one, it is likely to have better performance. But when the routing between nRF9160 and antenna, such as a long coaxial cable, and the desirable radiation properties of the terminal antenna are considered, the difference in the performance of an external and a properly designed internal antenna becomes quite small. Usually the design constraints exclude the use of an external antenna. As the dimensions of the board and layout mainly determine the performance of an integrated antenna, antenna design should be considered in the device concepting phase.

3.1 Off-the-shelf antennas

A variety of different antennas is available for terminal devices. Using off-the-shelf antennas is highly recommended due to the verified proof of concept performance, reduced antenna design costs, and design support provided by antenna manufacturers. Some antenna vendors also offer antenna tuning and testing on customer devices.

Some examples of antennas from different vendors are listed in Table 3: Examples of off-the-shelf antennas on page 9. These antennas have typical terminal antenna performance and can be used as a reference when selecting an antenna. To reach good antenna performance, the layout and placement recommendations in the antenna datasheets should be followed.

Vendor	Product	Part number	Frequency bands (MHz)
Ignion	TRIO mXTEND™ Mobile IoT Antenna	FR01-S4-210	698-960 1710-2690
Johanson Technology	LTE Multi-Band Ceramic Antenna	0830AT54A2200	700-800 1700-2100 824-960 1710-2690
Ethertronics	Universal Broadband FR4 Embedded LTE	P822601	698-960 1710-2200 2500-2700
Molex	698MHz-2.7GHz Cellular Ceramic Antenna	206760-0001	698-960 1700-2700
Antenova	Inversa – compact high performing antenna	SR4L034-L / SR4L034-R	698-798 824-960 1710-2170 2300-2400 2500-2690
Linx Technologies	CER Series Ceramic LTE Chip Antenna	ANT-LTE-CER	698-960 1710-2170 2300-2400 2500-2700
Taoglas	Minima Embedded Flexible 4G LTE Wide Band Antenna	FXUB65.07.0180	700-960 1700-2700

Table 3: Examples of off-the-shelf antennas

3.2 Antenna performance on device level

Regardless of the antenna type, some general antenna design guidelines should be followed to reach good antenna performance. More detailed antenna specific requirements are provided in the relevant antenna datasheets.

The dimensions of the ground plane and the placement of the antenna on it may have a significant impact on the performance of the antenna. Also, ground clearance around the antenna and conducting objects near it have an impact on the antenna's performance. For example, mounting screws should not be placed next to the radiator. Placing noisy components next to the antenna should be avoided. In addition to conductors, insulating materials near the antenna impact the antenna performance. Thick, lossy cover on top of the radiator can detune the antenna and increase performance losses significantly.

As the antenna may be sensitive to nearby materials as well as components on the *PCB*, antenna tuning should be done on a device in its final assembly when the battery and casing are in place.

Typically, antenna parameters are evaluated in free space that is different from the environment in which it is used. The device can, for example, be held in hand or mounted on a conductive wall. This should be considered when selecting a suitable antenna for the device. Some antenna designs may have worse performance in free space than others, but due to a minor detuning effect of nearby objects, the performance in actual use can be better.

3.3 Custom and active antenna designs

When wide bandwidth and minimal device size are required, a custom antenna may be needed rather than a conventional off-the-shelf antenna. Custom antennas may need to be optimized for device mechanics to reach adequate antenna performance. In these cases, there are antenna design houses that provide services to create customized solutions.

Another option is to use active antenna solutions. Despite the added complexity, antenna tuners or active antennas may improve the overall system performance significantly. With tuners, antenna input matching can be optimized for the frequency of operation. Some active antennas have tunable resonant frequency which enables the covering of a wide band set with a small narrowband antenna. nRF9160 provides control for antenna tuners. For more information, see External RF control on page 18.

> **Note:** If a custom antenna is chosen, it is important to measure the antenna characteristics when the first prototype is available.

3.4 Multiple antennas and interoperability

When multiple radios are supported in the same device, interference between the transceivers and the coupling between the antennas must be minimized. Radios can be isolated in frequency, time, and space. Polarization mismatch between antennas increases the isolation of the antennas.

The coupling between antennas on a shared *PCB* can be minimized by choosing the least interacting antenna types and locating the antennas on the shared *PCB* so that isolation between the antennas is maximized. It is important to consider all the antennas of the device early in the design phase. Otherwise, for example, performance drawbacks in sensitivity or spurious emissions may occur. If the antennas are not sufficiently isolated, additional filters and switches may be needed in the RF paths to reduce interference. The nRF9160 LTE modem and *GPS* receiver can be isolated from companion RF radios in time domain by COEX controls.

4 GPS interface and antenna

nRF9160 includes a *GPS* (*L1 C/A*) receiver with a SE 50 Ω RF interface (*GPS* pin). The *GPS* receiver can be active when the LTE modem is inactive or in power saving mode.

The *GPS* input of nRF9160 includes ESD components, but external active components may require ESD filtering. The instructions in the component's datasheet should be followed. The *GPS* input is *DC* grounded.

> **Note:** It is not recommended to use the *GPS* receiver without an external *Low-Noise Amplifier (LNA)* since it causes a sensitivity drawback of a few dBs.

Using matching components in the antenna output is recommended to ensure a good impedance match. *High-Q* and tight tolerance components should be used. For information on the recommended matching circuit and layout of each antenna, see the relevant *GPS* antenna datasheets.

There are several different alternatives for *GPS* front-end implementation. Some examples of them are described in detail in Dedicated GPS antenna with LNA module on page 12, Combined GPS and LTE antenna on page 14, and Active GPS antenna module on page 16. In other implementations than Combined GPS and LTE antenna on page 14, having a filter in the external *LNA* input is highly recommended to filter out high power LTE transmit signals as it may lead to, for example, an increase in radiated spurious emissions or deterioration in the sensitivity of the *GPS* receiver.

To avoid RF issues, 30 dB isolation at LTE TX frequencies between the nRF9160 ANT pin and the *GPS* input pin should be targeted. In other words, the maximum allowed coupling from the ANT pin to the *GPS* input pin at a maximum LTE transmit power of 23 dBm is -7 dBm. Coupling should be minimized on the *PCB*. An additional RF switch may be used instead of a filter in the *GPS* front-end to reach the required attenuation to LTE TX frequencies in the *LNA* input. However, a switch does not provide rejection against external interference sources, such as *Bluetooth*®, WLAN, and mobile networks, and therefore a *GPS Band-Pass Filter (BPF)* is recommended in the *LNA* output if an RF switch is chosen in the *GPS LNA* input.

To minimize power consumption, an external *LNA* should be supplied only when the *GPS* is active. The COEX0 pin can be configured to be high state during *GPS* receive. Thus, COEX0 can be used to control external *LNA*. For more information, see nRF91 AT Commands Reference Guide. In the *GPS* front-end implementation examples in Dedicated GPS antenna with LNA module on page 12, Combined GPS and LTE antenna on page 14, and Active GPS antenna module on page 16, COEX0 is used as *GPS LNA* enable and VDD_GPIO for *LNA* supply.

> **Note:** Noise filtering capacitors may be required on *GPS* supply and enable. Noise can be coupled to these lines on the device *PCB*. As the COEX interface conducts VDD_GPIO noise, additional filtering capacitors are recommended.

4.1 GPS antenna requirements

To reach optimized *GPS* sensitivity, a high-efficiency antenna and external *LNA* are needed. *GPS* front-end, antenna, and the characteristic impedance of the *GPS* transmission line must be 50 Ω to minimize mismatch losses.

A *GPS* signal is broadcast by satellites with *Right Hand Circular Polarization (RHCP)*. If the orientation of the device in actual use can be pre-defined, selecting an *RHCP* antenna that has a directive radiation pattern with maximum gain towards the sky may be advantageous. Due to multipath propagation, the angle of arrival may vary significantly in some environments.

Polarization may differ when the signal reaches the device. Therefore, a linearly polarized terminal *GPS* antenna with a relatively low maximum gain typically offers adequate antenna performance. Antenna efficiency should be as high as possible, but a minimum of 50 %. The *GPS* antenna and front-end requirements are summarized in the following table.

Parameter	Requirement	Note
50 Ω impedance, antenna VSWR	<2:1	Recommendation
	<3:1	Absolute requirement
50 Ω impedance, antenna *RL*	>9.5 dB	Recommendation
	>6.0 dB	Absolute requirement
Efficiency	>50 %	Recommendation
LTE TX rejection	>30 dB	Absolute requirement between the ANT and *GPS* pins and a recommendation between the LTE antenna and external *GPS LNA* input. Note the impact of both the antenna and layout.
LNA gain	>15 dB	Recommendation
Maximum *LNA Noise Factor (NF)*	1.0 dB	Recommendation
Maximum *LNA* filter module *NF*	1.5 dB	Recommendation

Table 4: GPS antenna and front-end requirements

A dedicated *GPS* antenna or combined LTE and *GPS* antenna can be chosen.

In both cases, the LTE TX attenuation requirement in the *GPS* input must be met. Examples of *GPS* antennas are listed in the following table.

Vendor	Product	Part number	Note
Abracon	1575MHz *GPS* Ceramic Chip Antenna	ACAG0301-1575-T	Miniature ceramic chip antenna (SMD) with linear polarization
Pulse	*GPS* L1 Band & GLONASS Ceramic Patch Antenna	-	Ceramic patch *RHCP* antenna, manual soldering
Ignion	TRIO mXTEND	FR01-S4-210	SMT chip antenna component. Can be tuned to cover LTE and *GPS* with adjusted matching network.

Table 5: GPS antenna examples

4.2 Dedicated GPS antenna with LNA module

To fulfill the 30 dB isolation between the LTE antenna and *GPS LNA* input, a filter may be needed in the *GPS LNA* input if the antenna isolation between the LTE and *GPS* antenna is less than 30 dB. The minimum attenuation requirement for the filter depends on the isolation between the LTE and *GPS* antennas and relaxes as the antenna isolation increases. Coupling between closely spaced antennas may be very strong even though they are targeted to operate at different frequencies.

A low *NF* and high gain of *LNA* ensure high *GPS* sensitivity. A minimum of 15 dB *LNA* gain and a maximum of 1 dB *NF* gain for *LNA* only are reasonable targets. For a combined *LNA* and filter module, the *NF* target is 1.5 dB.

To reach as low as possible total *NF*, the losses before the *LNA* input should be minimized. In layout design, this means placing the *LNA* as close as possible to the *GPS* antenna and minimizing the length of the transmission line between the antenna and the *LNA*.

4.2.1 Dedicated GPS antenna with LNA module example

An example of an implementation with a dedicated *GPS* antenna and *LNA* module is shown in Figure 3: Dedicated GPS antenna and LNA module on page 13.

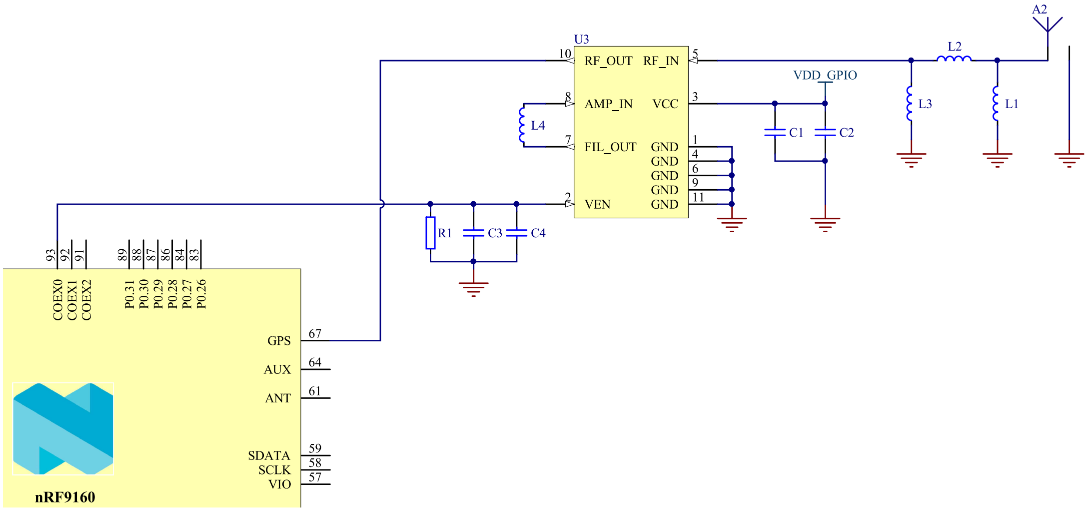

Figure 3: Dedicated GPS antenna and LNA module

Reference	Description
L1	Antenna matching
L2	Antenna matching
L3	Antenna matching
L4	9.1 nH, *LNA* input matching inductor
C1	100 nF, *LNA* power supply filtering capacitor
C2	100 pF, *LNA* power supply filtering capacitor
C3	100 nF, *LNA* enable filtering capacitor
C4	*LNA* enable filtering capacitor
R1	1 MΩ, pull-down resistor
U3	*Global Navigation Satellite System (GNSS)* front-end module
A2	ACAG0301-1575-T ceramic chip antenna

Table 6: Components of antenna interface with dedicated GPS antenna and LNA module

The following components are highlighted in Figure 4: Layout with dedicated GPS antenna and LNA module on page 14:

1. *GPS* front-end module
2. Antenna matching network
3. Dedicated *GPS* antenna
4. Antenna keep-out area

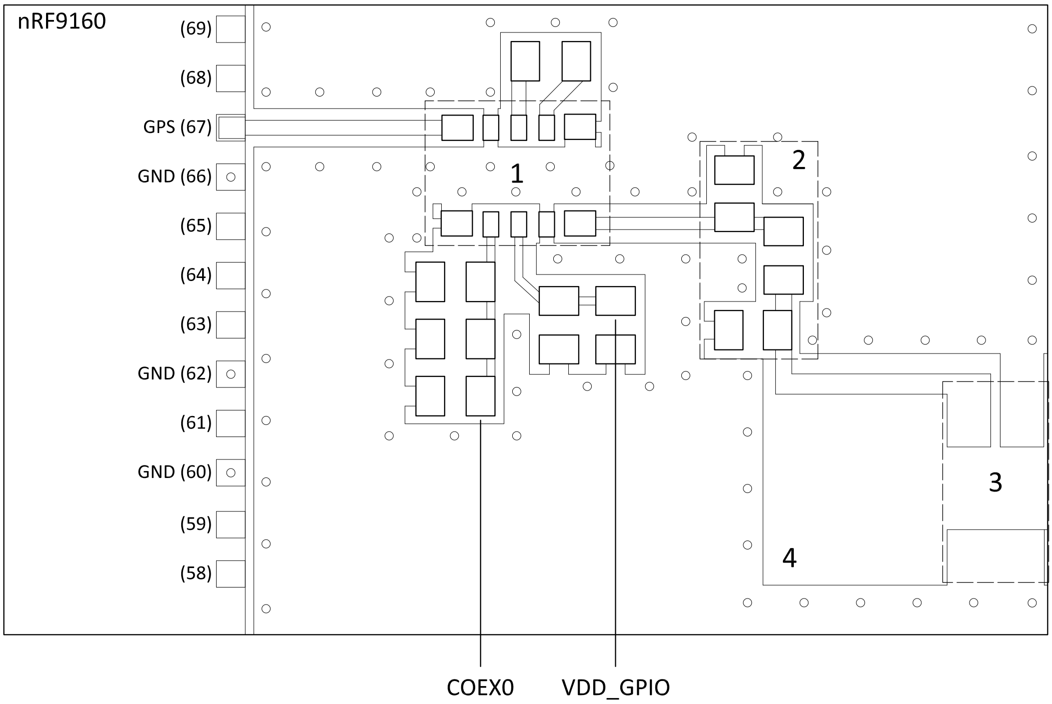

Figure 4: Layout with dedicated GPS antenna and LNA module

4.3 Combined GPS and LTE antenna

Depending on the device concept, tuning the LTE antenna to cover *GPS* may be advantageous. The *GPS* antenna requirements specified in Table 4: GPS antenna and front-end requirements on page 12 apply also to the combined *GPS* and LTE antenna at *GPS* frequency. To fulfil the LTE TX band rejection requirement, a switch is needed to isolate the *GPS* input from the LTE transmitter.

nRF9160 includes a 50 Ω RX auxiliary (AUX) path that can be used to loop back the signal fed into the ANT pin. The AUX can be used when two radios share an antenna. In case of a combined *GPS* and LTE antenna, an internal RF switch in nRF9160 provides the needed isolation between the *GPS* and LTE paths. When the *GPS* receiver is on, the antenna is switched to the AUX and through an external *LNA* to the *GPS* input. To minimize mismatch losses, using external matching components between AUX and *LNA* is recommended.

4.3.1 Combined GPS and LTE antenna example

An example of an implementation with a combined *GPS* and LTE antenna is shown in Figure 5: GPS implementation with combined LTE and GPS antenna on page 15.

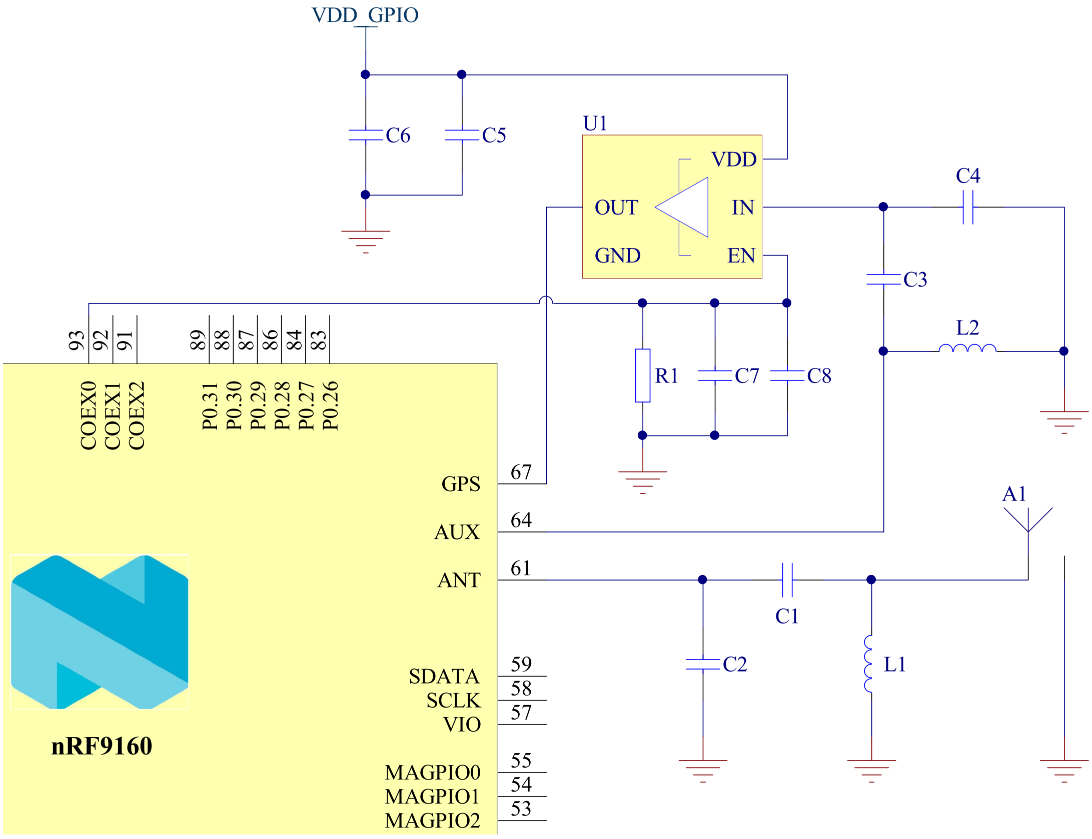

Figure 5: GPS implementation with combined LTE and GPS antenna

Reference	Description
L1	Antenna matching
L2	*LNA* input matching
C1	Antenna matching
C2	Antenna matching
C3	*LNA* input matching
C4	*LNA* input matching
C5	*LNA* supply filtering capacitor
C6	*LNA* supply filtering capacitor
C7	100 nF, *LNA* enable filtering capacitor
C8	100 pF, *LNA* enable filtering capacitor
R1	1 MΩ, pull-down resistor
U1	*LNA*
A1	Combined LTE and *GPS* antenna

Table 7: Components of GPS implementation with combined LTE and GPS antenna

Note: As a lower loss before the *LNA* ensures a better sensitivity in the *GPS*, routing from the antenna to the ANT and from the AUX to the *LNA* input should be kept as short as possible and *LNA* prefilter is not recommended.

When *GPS* is active, the AUX can be configured to be deployed during active *GPS* for *GPS* by an AT command. For more information, see nRF91 AT Commands Reference Guide.

4.4 Active GPS antenna module

A variety of active *GPS* modules including the antenna, *LNA*, and LTE TX rejection filter is available. Using an active *GPS* antenna module is typically a simple design solution as only a 50 Ω transmission line from module to nRF9160 *GPS* input and supply to *GPS* module must be provided.

Typically, active *GPS* antenna modules are a preferable choice due to their known performance. Modules with LTE TX filtering in the *LNA* input should be selected, as the LTE TX isolation requirement is difficult to achieve solely by antenna design in a small device.

4.4.1 Active GPS antenna module example

In active *GPS* modules, *LNA* supply input is typically combined with RF output. Therefore, a *DC* decoupling capacitor (C2) in the RF line and an RF choke inductor (L1) in the supply line are required. Using a capacitor (C1) with an RF choke inductor for RF grounding is recommended.

Additional supply filtering capacitors may be used to suppress noise in the supply. It is recommended to minimize current consumption by providing *GPS* module supply only when the *GPS* is active, for example by switching supply on and off by COEX0 signal. Load switch is a simple solution for this purpose.

An example of the implementation is shown in Figure 6: GPS implementation with active GPS module on page 16.

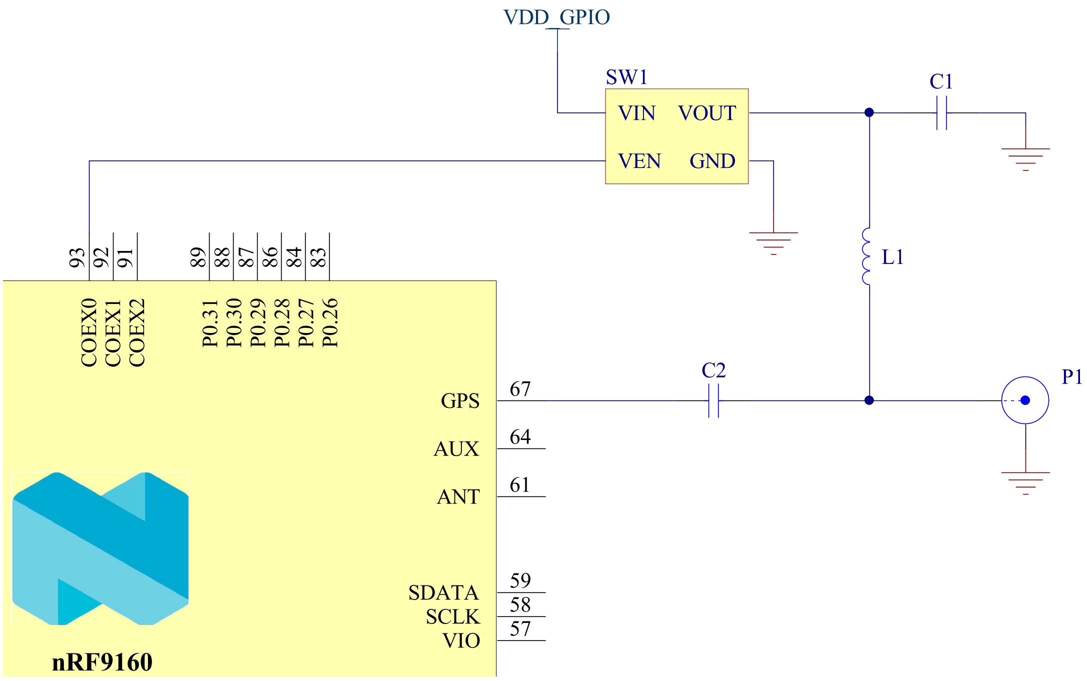

Figure 6: GPS implementation with active GPS module

Reference	Description
L1	RF choke inductor, 68 nH
C1	RF grounding capacitor, 56 pF
C2	*DC* block capacitor, 56 pF
SW1	Load switch
P1	Connector for active *GPS* module

Table 8: Components of GPS implementation with active GPS module

Note: As the active *GPS* antenna module includes an antenna, the position of the active *GPS* antenna module in the device is critical. Guidance for the placement of the *GPS* antenna module provided in the *GPS* antenna module datasheet must be followed.

Some active *GPS* modules have outputs for external matching components that can be used to tune the antenna. Examples of active *GPS* modules are listed in the following table.

Vendor	Product	Description
Antenova	M20057-1 SMD Active *GNSS* Antenna	SMT
Taoglas	AP.17F.07.0064A 17mm Two Stage *GPS*/Galileo Active Patch Antenna Module	I-PEX

Table 9: Examples of active GPS modules

5 External RF control

To avoid RF interference to a companion device, for example, Bluetooth Low Energy or *GNSS*, nRF9160 has a coexistence interface which enables time multiplexing between radios.

Coexistence inputs and outputs can be configured by AT commands. For more information on the coexistence interface, supported configurations, and AT commands, see nRF91 AT Commands Reference Guide.

nRF9160 also includes *MIPI RF Front-End Control Interface (RFFE)* and Modem-Application General-Purpose Input/Output (MAGPIO) interfaces that provide time-accurate control of RF components and devices, such as antenna tuners. *MIPI RFFE* and MAGPIOs can be configured by AT commands. For more information, see nRF91 AT Commands Reference Guide.

> **Note:** Caution is needed when using *MIPI RFFE*. The capacitive load at SCLK or SDATA pins shall not exceed 15 pF, since a higher load increases the risk of unwanted behavior in nRF9160 and the *MIPI RFFE* interface.

5.1 Antenna tuners

Antenna tuners or active antennas may improve the overall system performance significantly. Typically, antenna tuners are used in size-limited devices to widen antenna bandwidth.

An antenna tuner can be used as an impedance tuner in the antenna input or as a part of a resonator to tune the antenna's resonant frequency. In both cases, the antenna tuner must be designed together with the antenna. Otherwise, the tuner's benefit may become minimal or even counteractive.

5.1.1 Antenna tuner examples

Figures Figure 7: Antenna interface with MAGPIO controlled antenna impedance tuner on page 19 and Figure 8: Antenna interface with MIPI RFFE controlled active antenna on page 19 show examples of antenna interfaces including nRF9160 and an antenna tuner.

In Figure 7: Antenna interface with MAGPIO controlled antenna impedance tuner on page 19, the MAGPIO interface is used to control the antenna impedance tuner. As three MAGPIOs are available, a maximum of eight states of the antenna tuner can be supported.

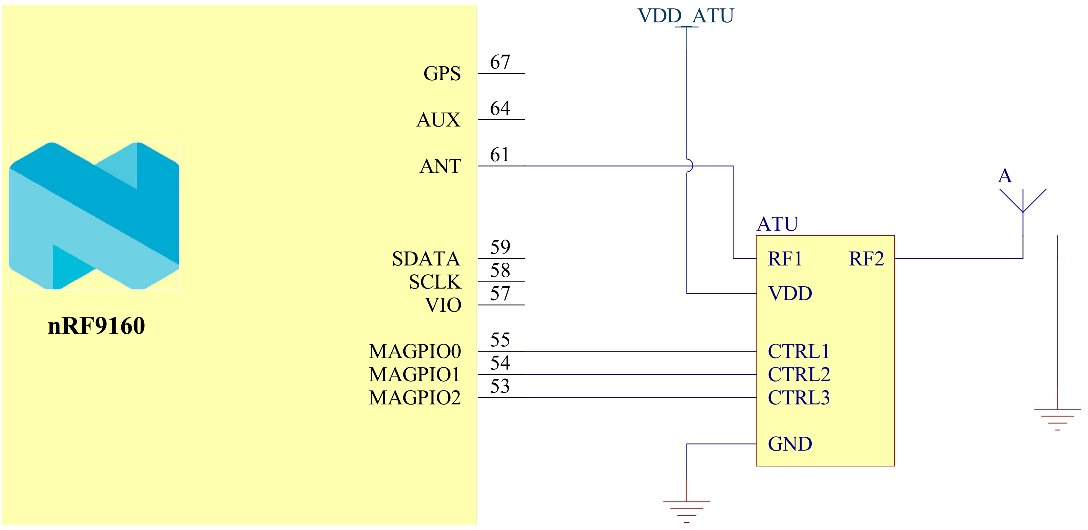

Figure 7: Antenna interface with MAGPIO controlled antenna impedance tuner

Figure 8: Antenna interface with MIPI RFFE controlled active antenna on page 19 shows the RF interface which includes nRF9160 and an antenna tuner controlled by *MIPI RFFE*. In *MIPI RFFE*, the number of different states is not limited by the number of available control lines. Therefore, it provides antenna tuners a more flexible control interface than MAGPIOs.

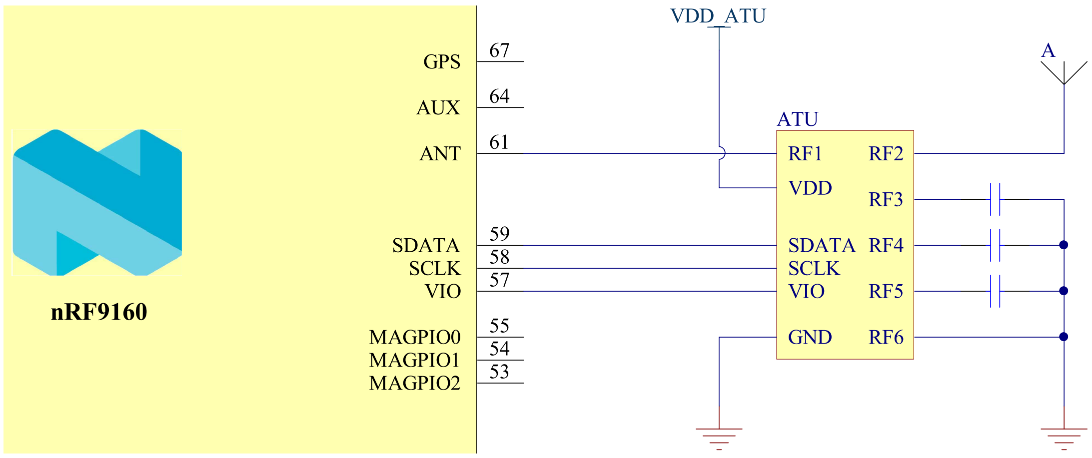

Figure 8: Antenna interface with MIPI RFFE controlled active antenna

6 Antenna and RF test

The RF testing of a device needs to be done in a controlled manner. The testing of an nRF9160 based device, for example, the enabling of an LTE transmitter at a certain channel, can be controlled in two ways:

- Through LTE protocol using an RF tester which controls the device through aerial (ANT pin) interface signaling
- By AT commands through UART interface in non-signaling mode

The non-signaling mode bypasses the LTE signaling protocol and is intended to be used only in controlled test environments. nRF9160 has inbuilt AT commands enabling the most relevant test modes for conductive and radiated tests for R&D and production. For more information about RF performance related test modes and other supported test capabilities, see nRF91 AT Commands Reference Guide.

> **Note:** AT test commands enable bypassing LTE signaling protocol and thus TX emissions. This feature is intended for use only in controlled test environments and shall not be used during normal module operation.

6.1 Conductive tests

The nRF9160 module is calibrated and verified for conductive performance. Conductive tests may be required in the development phase of the device or, for example, to verify a successful soldering of the pins in production. To be able to test the device in conductive mode, a test connector or RF cable needs to be connected to the nRF9160 antenna port (ANT).

To enable conductive tests in the development phase, reserving space in the layout for soldering a test cable is recommended. Adding a jumper in the antenna path may also be convenient. The jumper can be soldered in two positions. One is for connecting the nRF9160 ANT pin to the antenna, and the other one is for connecting the ANT pin to the test cable. This test option is included in Figure 11: Antenna presence test using GPIOs on page 23 and Figure 12: Layout of antenna presence test using GPIOs on page 24. Regardless of the test mode or layout options included in the device design, the 50 Ω impedance requirement in the nRF9160 ANT pin must be met.

A test connector can be used in the antenna RF transmission line. It is recommended to place it close to the nRF9160 ANT pin. Microwave coaxial switch connectors can be used for this purpose. In conductive tests, a test RF cable connects the nRF9160 ANT pin to the tester instead of the antenna. In actual use or radiated testing, the ANT pin is connected to the antenna. The layout for the connector must be designed to fulfill the 50 Ω requirement. For information on designing the connector layout for 50 Ω, see the connector datasheets. An antenna interface with an RF test connector is shown in Figure 9: Antenna presence test using MAGPIO on page 22 and Figure 10: Layout of antenna presence test using MAGPIO on page 23 .

6.2 Radiated tests

Radiated tests include the antenna and the device as in actual use. Therefore, radiated tests measure the actual RF performance of the device. Tests for measuring antenna performance and parameters are radiated tests but discussed in Antenna tests on page 21.

OTA testing is not mandatory in all cases of certification, but usually they are required, for example, by PTCRB and some operators. In spurious emission measurements, the level of interference caused by the device is verified to be under a certain level. The nRF9160 module has been verified to pass these tests in conductive mode, but in radiated mode strong coupling between the antenna and nonlinear components may lead to the creation of TX harmonics that exceed the allowed interference level. Thus, minimizing TX signal coupling from the antenna to other components to avoid failure in spurious emission tests is recommended. Total Isotropic Sensitivity (TIS) and Total Radiated Power (TRP) are active radiated measurements used to test transceivers' performance with the antenna.

In the TIS measurement, receiver sensitivity is measured over a three-dimensional sphere, and the result is averaged. Due to antenna loss, a mismatch loss between the antenna and receiver, as well as noise coupling from the device's board to the antenna, there is always some gap between TIS and conducted sensitivity.

In the TRP measurement, *OTA* transmitted power is measured over a three-dimensional sphere and summed to get the total radiated power. Antenna loss and mismatch loss between the antenna and transmitter drop the TRP results compared to conducted TX measurement results.

Active radiated measurements are time consuming. Therefore, antenna performance should be verified by passive antenna measurements before entering active tests.

Radiated functionality tests can be performed in non-signaling mode. This may be useful, for example, in production testing to verify the antenna's connection to the nRF9160 module as well as its basic functionality.

> **Note:** As the antenna emits RF power in radiated tests, the test environment must be controlled in both signaling and non-signaling tests to avoid interference and local regulations must be followed.

6.3 Antenna tests

To evaluate an antenna's standalone performance in a device, passive tests, such as antenna radiation pattern and basic antenna parameters over the operational bandwidth are performed. The radiated field of the antenna is measured in an anechoic chamber by varying the measurement angle to cover all directions with a certain angle step. From a three-dimensional field data, antenna parameters, such as efficiency and maximum gain, can be calculated. This applies also for different polarizations.

In passive antenna tests, the antenna is disconnected from the nRF9160 antenna pin (ANT) and connected to a test connector or test cable. Preserving space in the device layout for soldering a measurement cable is recommended.

> **Note:** Due to the many design and environment related factors impacting the antenna, antenna performance must be measured in the device's final assembly.

> **Note:** If the internal antenna is not tested by the antenna vendor or on a standalone reference board, it is important to measure the antenna characteristics as well as perform *OTA* testing once the first prototype of the device exists to guarantee performance and minimize the need for design changes in the certification phase.

6.3.1 Evaluation of RF exposure and SAR

RF energy that is radiated by wireless devices close to the user is partly absorbed by the human body and must not exceed safety limits. Devices that are used at a minimum of 20 cm's distance from the human body need to pass RF exposure evaluation in the certification process. Based on the declared maximum transmit power and maximum antenna gain of the device, the power density at 20 cm's distance is calculated not to exceed the allowed levels.

Devices that are used also at a distance of less than 20 cm from the user must go through *Specific Absorption Rate (SAR)* testing in which the power absorbed by human tissue is measured.

RF exposure evaluation, *SAR* testing, and test reports are provided by several accredited test houses worldwide.

6.4 Antenna presence test

An antenna presence test may be needed, for example, in the production testing of the device. nRF9160 supports antenna presence test for antennas that are *DC* grounded, which applies to several terminal antenna designs.

6.4.1 Antenna presence test using MAGPIO

One of the MAGPIOs can be deployed for the antenna presence test.

In the antenna presence test, a MAGPIO is *DC* connected to the antenna feed. Routing from the antenna line to the RF choke inductor (L1) should be kept as short as possible to minimize parallel stub in the antenna feed. The *DC* block capacitor (C1) prevents *DC* grounding of the test signals. C2 is an RF grounding capacitor. The antenna presence test is run by an AT command that can be found in nRF91 AT Commands Reference Guide. The MAGPIO to be used for the test is defined by the AT command.

An example of the implementation is shown in Figure 9: Antenna presence test using MAGPIO on page 22.

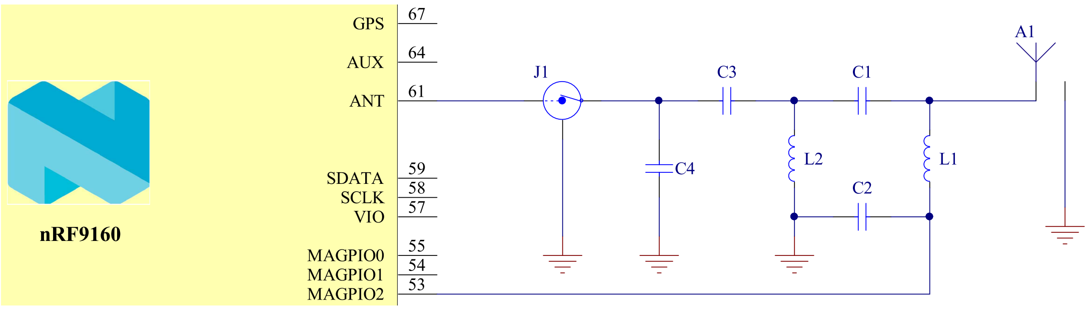

Figure 9: Antenna presence test using MAGPIO

Reference	Description
A1	Antenna, *DC* grounded
J1	Coaxial switch connector (Murata MM8130-2600)
L1	Antenna detection, RF choke inductor (56 nH)
L2	Antenna matching component (value depends on selected antenna)
C1	Antenna detection, *DC* block
C2	Antenna detection, RF grounding (56 pF)
C3	Antenna matching component (value depends on selected antenna)
C4	Antenna matching component (value depends on selected antenna)

Table 10: Components of antenna presence test using MAGPIO

The following components are highlighted in Figure 10: Layout of antenna presence test using MAGPIO on page 23:

1. Test connector
2. Antenna matching circuit

3. Antenna detection components
4. Antenna keep-out area

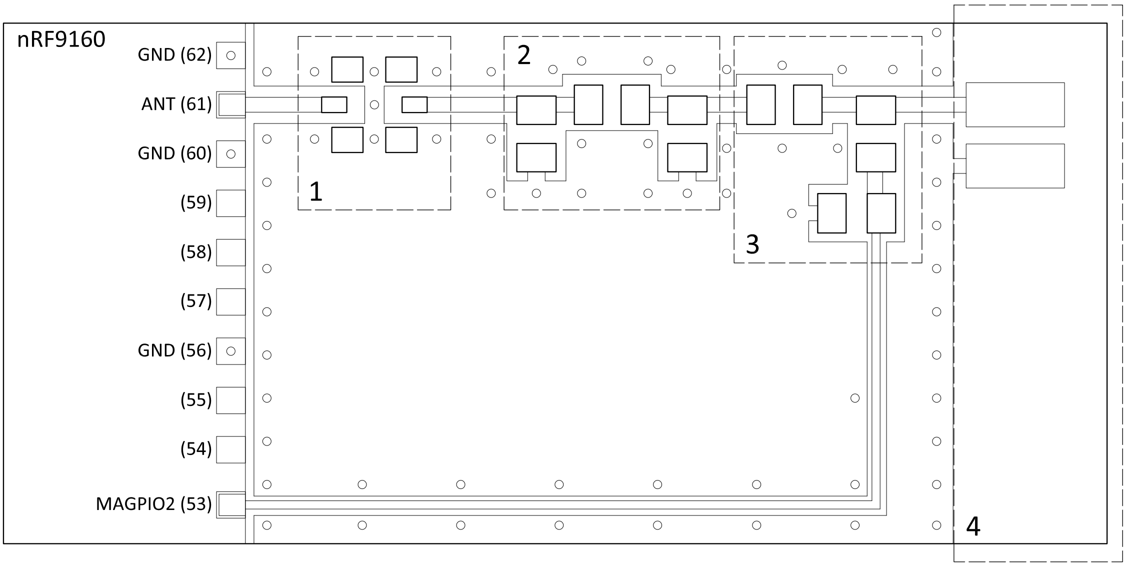

Figure 10: Layout of antenna presence test using MAGPIO

6.4.2 Antenna presence test using GPIOs

The antenna presence test can be implemented also in the application software side by deploying available *General-Purpose Input/Output (GPIO)*s.

One *GPIO* (P0.27) is configured as high output and connected to the antenna feed through a resistor (R3) and RF choke inductor (L1). Another *GPIO* (P0.26) is used to read the *DC* level of the antenna feed. If the *DC* level is low, the antenna is *DC* grounded and connected.

An example of the implementation is shown in Figure 11: Antenna presence test using GPIOs on page 23.

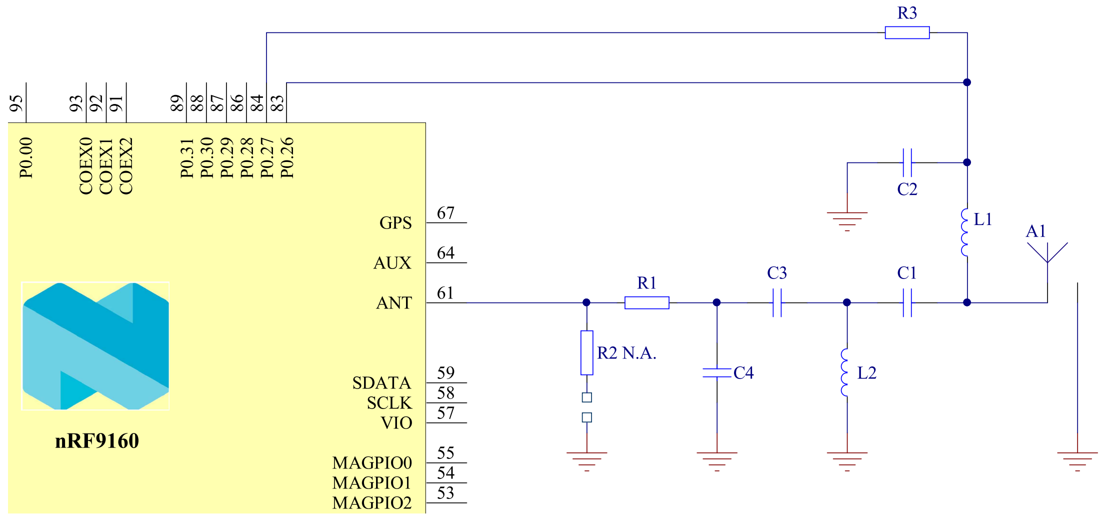

Figure 11: Antenna presence test using GPIOs

Reference	Description
A1	Antenna, *DC* grounded
R1	0R
R2	0R, not assembled by default
R3	Antenna detection resistor (10 kΩ)
L1	Antenna detection, RF choke inductor (56 nH)
L2	Antenna matching component (value depends on selected antenna)
C1	Antenna detection, *DC* block
C2	Antenna detection, RF grounding (56 pF)
C3	Antenna matching component (value depends on selected antenna)
C4	Antenna matching component (value depends on selected antenna)

Table 11: Components of antenna presence test using GPIOs

The following components are highlighted in Figure 12: Layout of antenna presence test using GPIOs on page 24:

1. Test cable
2. Antenna matching circuit
3. Antenna detection components
4. Antenna keep-out area

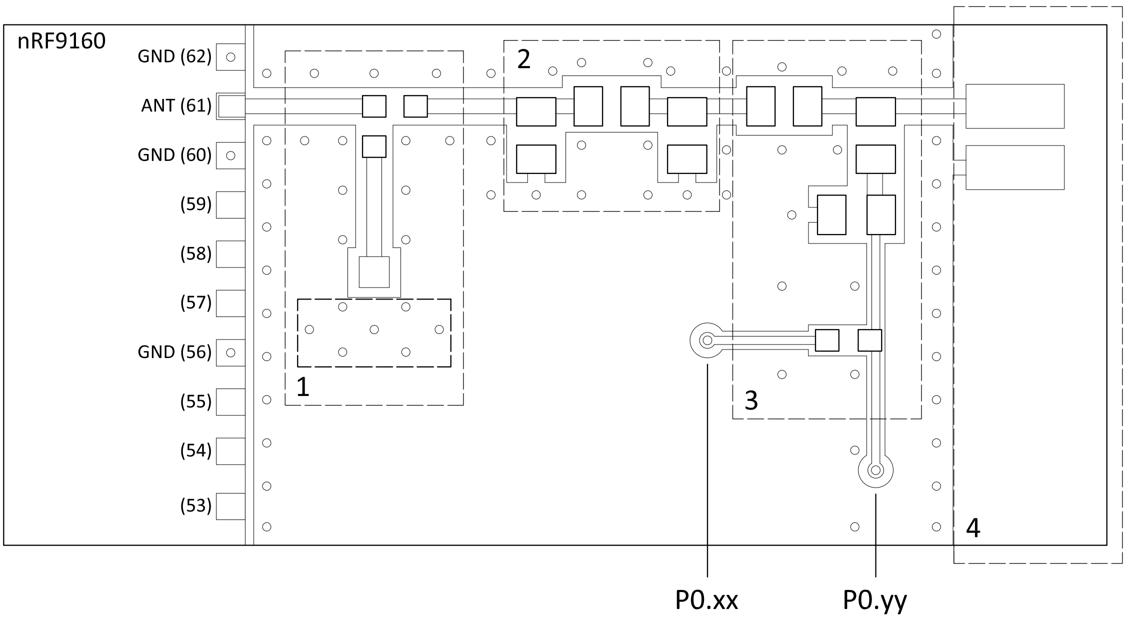

Figure 12: Layout of antenna presence test using GPIOs

Glossary

Band-Pass Filter (BPF)

An electronic device or circuit that passes frequencies within a certain range and rejects frequencies outside that range.

DC

Direct Current

Global Navigation Satellite System (GNSS)

A satellite navigation system with global coverage. The system provides signals from space transmitting positioning and timing data to GNSS receivers, which use this data to determine location.

General-Purpose Input/Output (GPIO)

A digital signal pin that can be used as input, output, or both. It is uncommitted and can be controlled by the user at runtime.

Global Positioning System (GPS)

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

High-Q

Quality factor of an inductor or capacitor defined as the relation between its reactance and series (parasitic) resistance.

L1 C/A

GPS signal broadcast by *GPS* satellites.

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.

MIPI RF Front-End Control Interface (RFFE)

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

Noise Factor (NF)

The relation of the *Signal-to-Noise Ratio (SNR)* in the device input to the *SNR* in the device output.

Over-the-Air (OTA)

Refers to any type of wireless transmission.

Printed Circuit Board (PCB)

A board that connects electronic components.

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.

Return Loss (RL)

The relation of incident power to reflected power typically expressed in dB. High return loss corresponds with low reflected signal level and good impedance matching.

Specific Absorption Rate (SAR)

The rate at which energy is absorbed by the human body when exposed to a radio frequency (RF) electromagnetic field or other forms of energy.

System in Package (SiP)

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

Signal-to-Noise Ratio (SNR)

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

Acronyms and abbreviations

These acronyms and abbreviations are used in this document.

BPF
Band-Pass Filter

DC
Direct Current

GNSS
Global Navigation Satellite System

GPIO
General-Purpose Input/Output

GPS
Global Positioning System

LNA
Low-Noise Amplifier

MIPI RFFE
MIPI RF Front-End Control Interface

NF
Noise Factor

OTA
Over-the-Air

PCB
Printed Circuit Board

RHCP
Right Hand Circular Polarization

RL
Return Loss

SAR
Specific Absorption Rate

SiP
System in Package

SNR
Signal-to-Noise Ratio

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