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<table>
<thead>
<tr>
<th>Date</th>
<th>Version</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 2019</td>
<td>1.0</td>
<td>First release</td>
</tr>
</tbody>
</table>
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.
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Ω impedance, antenna Voltage Standing Wave Ratio (VSWR)</td>
<td>&lt;2:1</td>
<td>Recommendation</td>
</tr>
<tr>
<td></td>
<td>&lt;3:1</td>
<td>Absolute requirement</td>
</tr>
<tr>
<td>50 Ω impedance, antenna Return Loss (RL)</td>
<td>&gt;9.5 dB</td>
<td>Recommendation</td>
</tr>
<tr>
<td></td>
<td>&gt;6.0 dB</td>
<td>Absolute requirement</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt;50%</td>
<td>Recommendation. Operators may have other efficiency requirements.</td>
</tr>
<tr>
<td>Maximum gain</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Maximum input power</td>
<td>1 W</td>
<td></td>
</tr>
</tbody>
</table>

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](image)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Antenna</td>
</tr>
<tr>
<td>L2</td>
<td>Antenna matching component</td>
</tr>
<tr>
<td>C1</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td></td>
</tr>
</tbody>
</table>

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

![Diagram of antenna interface example](image)

*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.
### Table 3: Examples of off-the-shelf antennas

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

### 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.
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Ω impedance, antenna VSWR</td>
<td>&lt;2:1</td>
<td>Recommendation</td>
</tr>
<tr>
<td></td>
<td>&lt;3:1</td>
<td>Absolute requirement</td>
</tr>
<tr>
<td>50 Ω impedance, antenna RL</td>
<td>&gt;9.5 dB</td>
<td>Recommendation</td>
</tr>
<tr>
<td></td>
<td>&gt;6.0 dB</td>
<td>Absolute requirement</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt;50 %</td>
<td>Recommendation</td>
</tr>
<tr>
<td>LTE TX rejection</td>
<td>&gt;30 dB</td>
<td>Absolute requirement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td>LNA gain</td>
<td>&gt;15 dB</td>
<td>Recommendation</td>
</tr>
<tr>
<td>Maximum LNA Noise Factor (NF)</td>
<td>1.0 dB</td>
<td>Recommendation</td>
</tr>
<tr>
<td>Maximum LNA filter module NF</td>
<td>1.5 dB</td>
<td>Recommendation</td>
</tr>
</tbody>
</table>

*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.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product</th>
<th>Part number</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abracon</td>
<td>1575MHz GPS Ceramic Chip Antenna</td>
<td>ACAG0301-1575-T</td>
<td>Miniature ceramic chip antenna (SMD) with linear polarization</td>
</tr>
<tr>
<td>Pulse</td>
<td>GPS L1 Band &amp; GLONASS Ceramic Patch Antenna</td>
<td>-</td>
<td>Ceramic patch RHCP antenna, manual soldering</td>
</tr>
<tr>
<td>Fractusantennas</td>
<td>TRIO mXTEND</td>
<td>FR01-S4-210</td>
<td>SMT chip antenna component. Can be tuned to cover LTE and GPS with adjusted matching network.</td>
</tr>
</tbody>
</table>

*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](image)

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

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 fulfill 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

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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Antenna matching</td>
</tr>
<tr>
<td>L2</td>
<td>LNA input matching</td>
</tr>
<tr>
<td>C1</td>
<td>Antenna matching</td>
</tr>
<tr>
<td>C2</td>
<td>Antenna matching</td>
</tr>
<tr>
<td>C3</td>
<td>LNA input matching</td>
</tr>
<tr>
<td>C4</td>
<td>LNA input matching</td>
</tr>
<tr>
<td>C5</td>
<td>LNA supply filtering capacitor</td>
</tr>
<tr>
<td>C6</td>
<td>LNA supply filtering capacitor</td>
</tr>
<tr>
<td>C7</td>
<td>100 nF, LNA enable filtering capacitor</td>
</tr>
<tr>
<td>C8</td>
<td>100 pF, LNA enable filtering capacitor</td>
</tr>
<tr>
<td>R1</td>
<td>1 MΩ, pull-down resistor</td>
</tr>
<tr>
<td>U1</td>
<td>LNA</td>
</tr>
<tr>
<td>A1</td>
<td>Combined LTE and GPS antenna</td>
</tr>
</tbody>
</table>
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](image)
<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>RF choke inductor, 68 nH</td>
</tr>
<tr>
<td>C1</td>
<td>RF grounding capacitor, 56 pF</td>
</tr>
<tr>
<td>C2</td>
<td>DC block capacitor, 56 pF</td>
</tr>
<tr>
<td>SW1</td>
<td>Load switch</td>
</tr>
<tr>
<td>P1</td>
<td>Connector for active GPS module</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenova</td>
<td>M20057-1 SMD Active GNSS Antenna</td>
<td>SMT</td>
</tr>
<tr>
<td>Taoglas</td>
<td>AP.17F.07.0064A 17mm Two Stage GPS/Galileo Active Patch Antenna Module</td>
<td>I-PEX</td>
</tr>
</tbody>
</table>

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.
External RF control

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
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.
Antenna and RF test

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](image)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Antenna, DC grounded</td>
</tr>
<tr>
<td>J1</td>
<td>Coaxial switch connector (Murata MM8130-2600)</td>
</tr>
<tr>
<td>L1</td>
<td>Antenna detection, RF choke inductor (56 nH)</td>
</tr>
<tr>
<td>L2</td>
<td>Antenna matching component (value depends on selected antenna)</td>
</tr>
<tr>
<td>C1</td>
<td>Antenna detection, DC block</td>
</tr>
<tr>
<td>C2</td>
<td>Antenna detection, RF grounding (56 pF)</td>
</tr>
<tr>
<td>C3</td>
<td>Antenna matching component (value depends on selected antenna)</td>
</tr>
<tr>
<td>C4</td>
<td>Antenna matching component (value depends on selected antenna)</td>
</tr>
</tbody>
</table>

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
6.4.2 Antenna presence test using GPIOs

The antenna presence test can be implemented also in the application software side by deploying available GPIOs.

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.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Antenna, DC grounded</td>
</tr>
<tr>
<td>R1</td>
<td>0R</td>
</tr>
<tr>
<td>R2</td>
<td>0R, not assembled by default</td>
</tr>
<tr>
<td>R3</td>
<td>Antenna detection resistor (10 kΩ)</td>
</tr>
<tr>
<td>L1</td>
<td>Antenna detection, RF choke inductor (56 nH)</td>
</tr>
<tr>
<td>L2</td>
<td>Antenna matching component (value depends on selected antenna)</td>
</tr>
<tr>
<td>C1</td>
<td>Antenna detection, DC block</td>
</tr>
<tr>
<td>C2</td>
<td>Antenna detection, RF grounding (56 pF)</td>
</tr>
<tr>
<td>C3</td>
<td>Antenna matching component (value depends on selected antenna)</td>
</tr>
<tr>
<td>C4</td>
<td>Antenna matching component (value depends on selected antenna)</td>
</tr>
</tbody>
</table>

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](image-url)
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.

**GPIO**
General-Purpose Input/Output

**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)**
A number of 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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