AirPrime RC Series GNSS Antenna System Requirements

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Author:	Sierra Wireless	**Date:**	October 05, 2020

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1 Version

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2 Introduction

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3 Glossary

Term/Initials	Definition
GNSS	Global Navigation Satellite System
LNA	Low Noise Amplifier
RHCP	Right hand Circular Polarized
LHCP	Left Hand Circular Polarized
BAW	Bulk Acoustic Wave
SAW	Surface Acoustic Wave
FBAR	Film Bulk Acoustic Resonator
FEM	Front End Module
CPW	Coplanar Waveguide
ESD	Electrostatic Discharge

4 Technical Note Description

This document provides integrators with guidelines to choose or design a suitable GNSS antenna system (passive or active GNSS antenna) for use with a Sierra Wireless AirPrime RC Series module. Many design choices depend on the expected radiated environment and the requirements of the overall GNSS application being developed so significant care must be taken to ensure the overall performance of the system.

5 Overview

AirPrime RC series modules include Global Navigation Satellite System (GNSS) functionality, capable of operation in assisted and standalone GNSS modes.

The RC LGA has a dedicated pin for the GNSS receiver input. A suitable on-board or off-board passive or active antenna can be routed to this pin to enable GNSS operation:

- Passive GNSS antenna – Can be used for typical small platforms.
- Active antenna – Can be employed for applications where the GNSS antenna is located far enough away from the modem that the insertion loss of the RF trace on the PCB or the coaxial cable between antenna and modem would significantly degrade the noise figure, and thus, the sensitivity, of the GNSS receiver. The active antenna must provide its own power supply.

6 RC Series GNSS Capabilities

The following table describes RC series modules and their GNSS capabilities:

Table 1: GNSS Band Support by RC Series

Series	Supported GNSS Constellations
RC7611	GPS L1 + Galileo E1 + GLONASS L1 + BeiDou B1
RC7620	GPS L1 + Galileo E1 + GLONASS L1 + BeiDou B1
RC7630	GPS L1 + Galileo E1 + GLONASS L1 + BeiDou B1 + QZSS L1

The following figures describe the block diagrams of the GNSS front-end design for the RC series modules.

The RC76 series modules use Qualcomm's MDM9x07+WTR2965 chipset. The WTR2965 GNSS receiver does not require an external LNA circuit.

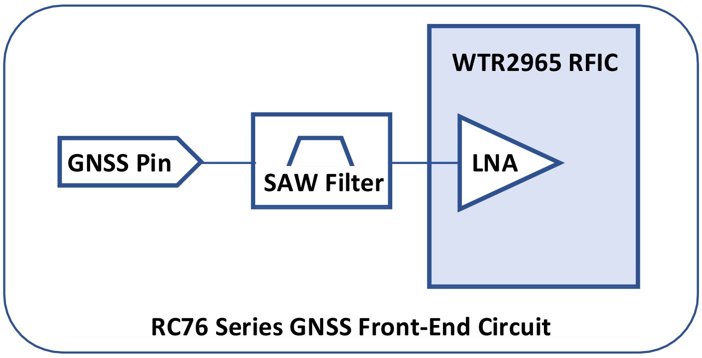

Figure 1. RC76 Series front-end circuit

The following table summarizes the RC modules' GNSS measured sensitivity using a single channel GPS signal generator. More complete specifications are provided in the corresponding AirPrime RC76xx Product Technical Specification document.

Table 2: RC Series GNSS Performance

	RC7611, RC7620, RC7630
Rx Noise Figure	4 dB
GPS Conducted Acquisition Sensitivity	-145 dBm
GPS Conducted Tracking Sensitivity	-160 dBm

7 Antenna – Passive vs. Active

Use of an appropriate GNSS antenna with the RC module is critical to its performance.

A passive GNSS antenna can be used on a platform where the antenna is located very close to the RC module. The insertion loss of the RF trace or coaxial cable between the antenna feed and the RC GNSS pin must be kept less than 0.5 dB for RC7620 and RC7611 series modules. Customers must test and verify if the performance of the GNSS receiver with a passive antenna meets their expectations.

Customers may decide to use an external low-noise amplifier (LNA) circuit close to the passive GNSS antenna on the platform's PCB to compensate for the excess insertion loss and noise figure. Moreover, specific applications may require an off-board active antenna, which is essentially a passive antenna with an integrated LNA circuit.

Note that even the best GNSS receiver requires a decent antenna element that is optimized for reception of GPS/GLONASS/Galileo/BeiDou/QZSS satellite signals. For open sky applications with line-of-sight signals, a right-hand circularly polarized (RHCP) antenna will likely be advantageous whereas for indoor or other non-line-of-sight applications with significant multi-path reflections, a linearly polarized antenna will likely suffice. The following table lists some examples of commonly used antenna types.

Table 3: Common GNSS Antenna Types

Antenna Type	Polarization	Comments
Helical	RHCP	• Commonly used in handheld devices • Excellent performance • Typically tall and/or bulky
Ceramic patch	RHCP	• Commonly used in active antennas and large form-factor devices • Good performance • Typically low profile
Monopole, IFA, chip	Linear	• Commonly used in cell phones and small devices • Acceptable performance • Smallest form factor

Like any other antenna, a GNSS antenna is required to meet certain specifications. The main parameters include the radiation pattern, gain, efficiency, bandwidth and impedance. The following table lists the recommended specifications of a suitable GNSS antenna. Some other important parameters will be discussed in later sections.

Table 4: GNSS Antenna Requirements

Parameter	Requirements	Comments
Frequency range	GPS L1 + Galileo E1 + GLONASS L1 + QZSS L1 — 1573–1606 MHz or GPS L1 + Galileo E1 + GLONASS L1 + BeiDou B1 + QZSS L1 — 1559–1606 MHz	Wide-band antenna is not desired.
Field of view (FOV)	Omni-directional in azimuth -45° to +90° in elevation	Extended upper-hemisphere coverage
Polarization	RHCP or Linear	LHCP is not acceptable.
Polarization (average Gv/Gh)[a]	> 0 dB	Linear polarization is sufficient.
Free space average gain (Gv+Gh) over FOV	> -6 dBi (preferably > -3dBi)	• Gv and Gh are measured and averaged over -45° to +90° in elevation, and 180° in azimuth. • Maximum gain and uniform coverage in the high elevation angle and zenith. • Gain in azimuth plane is not desired.
Efficiency	> -4 dB (preferably > -3 dB)	
Typical VSWR	> 2.5:1 (preferably < 2:1)	
Power handling	> +26dBm	The antenna radiator is a passive element, but this requirement is to ensure that the element can withstand the radiated Tx power from the module's WWAN antenna or other strong interference signals.

a. Gh: horizontal polarization gain; Gv: vertical polarization gain

8 Other Active and Passive Components

As mentioned in the previous section, customers may decide to use an external LNA circuit close to the passive GNSS antenna on the platform's PCB to compensate for the excess loss and noise figure. Moreover, specific applications may require an off-board active antenna. An active antenna is essentially a passive antenna with an LNA circuit.

The following block diagrams show an onboard LNA circuit and an off-board active antenna. For both cases, the circuit is comprised of a number of components between the passive antenna element and the RC module. These components include a low noise amplifier (LNA), a filter, and PCB RF traces for an onboard LNA or an RF coaxial cable and connector for an active antenna.

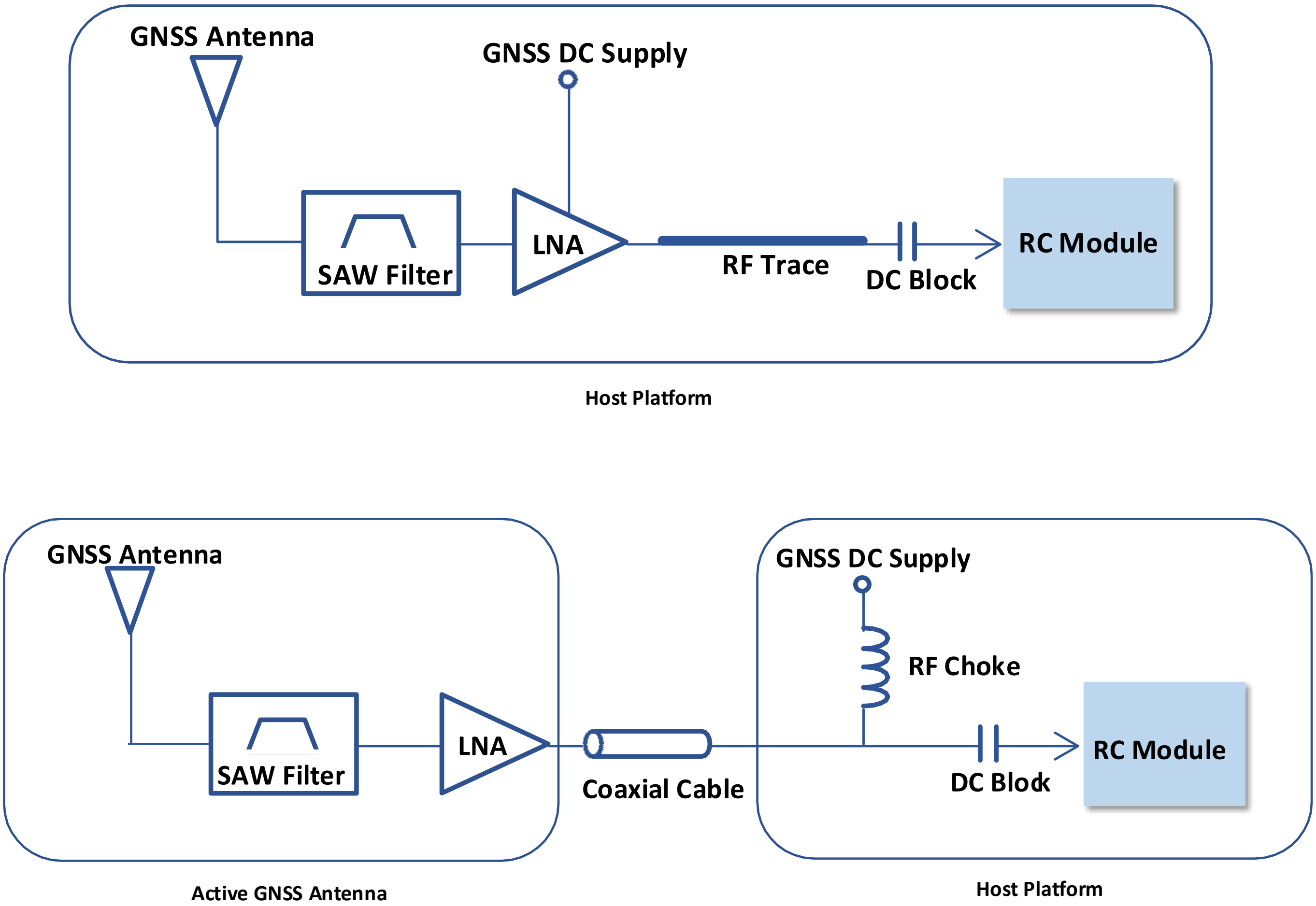

Figure 2. Host Platform

8.1 LNA

The LNA (low noise amplifier) is used to control the system noise figure by providing sufficient low noise amplification of the GNSS signals prior to the insertion loss (in this case, the excess noise figure) of any post-LNA circuit and/or RF trace or coaxial cable.

The LNA also mitigates any degradation in GNSS sensitivity that could result from external interfering signals coupling onto the cable or the modem by boosting the wanted signal level compared to that of the interfering signals.

LNA parameters are described below, including important parameters (noise figure, gain, linearity) and less critical parameters (voltage, current).

8.1.1 LNA Noise Figure

While LNA noise figure is not the only factor that drives the minimum detectable signal, it is an important consideration since the noise figure of the first stage in a receiver chain is the main contributor to the system noise figure. A good single-stage commercial grade GNSS LNA has a noise figure below 1 dB. It is important to note that the LNA circuit must be placed very close to the antenna feed, otherwise the total noise figure of the GNSS receiver, and as a result its sensitivity, will be adversely impacted.

8.1.2 LNA Gain

It is important to choose an LNA with the required amount of gain rather than the highest available gain, since more gain will produce more intermodulation products in the LNA and the receiver. The gain of a single stage LNA is typically around 15 dB.

It is desirable to use an LNA with sufficient bandwidth to cover the GNSS band. Wide-band LNAs are not recommended.

8.1.3 LNA Linearity

Since signals other than the wanted GNSS signals can be present at the input, the linearity of the LNA must be carefully considered.

- A strong signal present at the input of the LNA can drive the amplifier into compression, which has the unwanted effect of reducing the gain, and thus the signal to noise ratio for the GNSS signal.
- When two or more strong signals are present at the input of the LNA, the signals can mix to create intermodulation products. Some of these products can fall in the GNSS band and cause interference.

The recommended “input 1 dB gain compression point” of a GNSS LNA is -10 dBm or higher, and the recommended out-of-band “third-order input intercept point” is +1 dBm or higher.

8.1.4 LNA Supply Voltage and Current

The onboard LNA requires a bias voltage that is provided by the host platform. A low-noise linear regulator is recommended for the LNA supply. It is advised to place additional noise filtering at the input and output of the linear regulator and also on the supply pin of the LNA. The supply voltage of typical GNSS LNAs is 1.8V to 3V and their current consumption is less than 10 mA.

The off-board active antenna also needs a bias voltage for its built-in LNA. As with the onboard LNA, this DC voltage must be provided by the host platform. The LNA voltage is fed to the center conductor of the active antenna coaxial cable, which also carries the amplified GNSS signal from the antenna to the RC module. Since the GNSS RF signal and the low-impedance DC voltage share the same path, the DC voltage must have a series RF inductor (RF choke) of at least 33 nH or higher in order to not affect the RF signal.

The supply voltage of typical active antennas is 3V to 5V and their current consumption is less than 100 mA.

Note that for the case of the active antenna, the voltage drop due to the DC resistance of the coaxial cable and the RF choke on the LNA supply line must also be considered when calculating the available supply voltage at the LNA terminals.

Also, note that any external DC voltage at the RC GNSS input should not exceed 5V. In addition to the series capacitor inside the module on the RC GNSS input, a series DC decoupling capacitor (~100 pF) should be placed at the GNSS input.

The following table lists the recommended specifications of a GNSS LNA.

Table 5: GNSS LNA Requirements

Parameter	Requirements	Comments
Frequency range	1559–1606MHz	Wide-band LNA is not desired.
Supply voltage	< 5V	
Current consumption	< 10mA	
Power Gain	14~17dB (1559–1606MHz)	
Noise Figure	< 1 dB (1559–1606MHz)	
VSWR (in/out)	< 2:1 (1559–1606MHz)	
700 MHz harmonic	< -50 dBm	Input jammer – 777/787.5 MHz at -25 dBm Measure the harmonic at 1554/1575 MHz.
Input 1 dB compression point	-10 dBm (1559–1606 MHz)	
Input second- order intercept point IIP2 (out- of-band)	> +45 dBm	Input jammer: • 824.6 MHz at -25 dBm • 2400 MHz at -32 dBm • Output IM2 at 1575.4 MHz
Input third-order intercept point IIP3 (out-of-band)	> +1dBm	Input jammer: • 1712.7 MHz at -20dBm • 1850 MHz at -65dBm • Output IM3 at 1575.4 MHz

8.2 Band-Pass Filter

The RC module has a built-in high performance SAW (surface acoustic) band pass filter with low insertion loss and high out-of-band attenuation. For the external LNA circuit, band-pass filtering is required in order to attenuate the out-of-band interference that can degrade the LNA performance. For this purpose, a GNSS SAW filter with low insertion loss and good out-of-band rejection is recommended at the input of the LNA. The following table lists the recommended GNSS SAW filter specifications.

Note: Other types of band pass filters such as BAW (bulk acoustic wave) and FBAR (film bulk acoustic resonator) filters can be employed as long as they meet the minimum specifications.

Table 6: GNSS SAW Filter Requirements

Parameter	Requirements	Comments
Pass Band	1559.05–1605.89 MHz	GPS L1, Galileo E1, BeiDou B1, GLONASS L1, QZSS L1
Insertion Loss	< 1.5 dB (1559.05–1605.89 MHz)	
Return Loss (in/out)	> 15 dB (1559.05–1605.89 MHz)	
Absolute attenuation	> 45 dB (10–915MHz) > 35 db (915–1463MHz) > 40 db (1710–2700MHz)	
700 MHz harmonic	< -110 dBm	Input jammer – 777/787.5 MHz at +15 dBm Measure the harmonic at 1554/1575 MHz.
Power handling	> +15 dBm (Continuous)	Coupled from WWAN transmitter

8.3 GNSS Front-End Module

A better alternative to the discrete LNA-SAW filter design (Figure 2), is the GNSS Front-End module (FEM).

The GNSS FEM is a very small LGA device (1.1mm x 1.5mm to 2.5mm x 2.5mm) that integrates a GNSS SAW filter with the LNA. The GNSS FEM can offer very good performance because the integrated LNA, SAW filter and their matching circuits have been co-designed for low noise figure, sufficient linearity and high out-of-band rejection.

Depending on the GNSS receiver architecture there are different types of GNSS FEM; some have the SAW filter at the LNA input, some have the SAW filter at the LNA output, and some have two SAW filters, one at the input and another one at the output of the LNA. The GNSS FEM that can be used with the RC as the onboard LNA circuit is the one that has the SAW filter at the LNA input.

The following table lists the recommended specifications of such a GNSS FEM:

Table 7: GNSS LNA FEM Requirements

Parameter	Requirements	Comments
SAW filter position	LNA input	
Pass Band	1559.05–1605.89 MHz	GPS L1, Galileo E1, BeiDou B1, GLONASS L1, QZSS L1
Supply voltage	< 5V	
Current consumption	< 10 mA	
Power Gain	14~17 dB (1559.05–1605.89 MHz)	
Noise Figure	< 2.5 dB (1559.05–1605.89 MHz)	
Impedance (in/out)	50 Ohms	
VSWR (in/out)	< 2:1 (1559.05–1605.89 MHz)	
700 MHz harmonic	< -85 dBm	Input jammer – 777/787.5 MHz at +15 dBm Measure the harmonic at 1554/1575 MHz. (To achieve this requirement, a high-Q LC notch filter is needed at the input of the GNSS FEM.)
Input 1 dB compression point	> -10 dBm (in-band) > +25 dBm (out-of-band)	
Input second-order intercept Point IIP2 (out-of-band)	> +85 dBm	Input jammer – 824.6/2400 MHz at +15 dBm Output IM2 at 1575.4 MHz
Input third-order intercept point IIP3 (out-of-band)	> +65 dBm	Input jammer tones – 1712.7/1850 MHz at +15 dBm Output IM3 at 1575.4 MHz
Absolute Attenuation	> 45 dB (777–915 MHz) > 35 db (915–1463 MHz) > 40 db (1710–2700 MHz)	

8.4 B13 Notch Filter

For RC modules that will need to operate in a jurisdiction that supports LTE Band 13, the B13 uplink signal (which is about half the GNSS frequency) will be picked up by the GNSS antenna.

Customers must:

- Provide sufficient antenna-to-antenna isolation, and
- Filter out the B13 uplink signal before it gets to the LNA

If these requirements are not satisfied, a high level of B13 second harmonic can be generated in the LNA. Since this harmonic falls in the GNSS band, it cannot be subsequently filtered and can significantly degrade the receiver sensitivity. The SAW filter out-of-band rejection can provide most of the B13 uplink attenuation, but to achieve the required harmonic rejection a ceramic notch filter or, as shown in Figure 4, a high-Q LC notch filter is recommended to provide an additional ~20dB attenuation.

Note: The notch filter is specifically for a GNSS antenna with an LNA circuit. RC modules that support LTE B13 have an internal notch filter to operate with a passive antenna. However, RC modules that do not support LTE B13 do not have an internal notch filter and thus are potentially susceptible to strong GNSS jamming by a nearby wireless device operating on B13.

Customers must test their RC module combined with the external LNA circuit for GNSS performance with concurrent LTE B13 traffic and, if necessary, tune the notch filter to minimize the GNSS desense due to the B13 uplink harmonic.

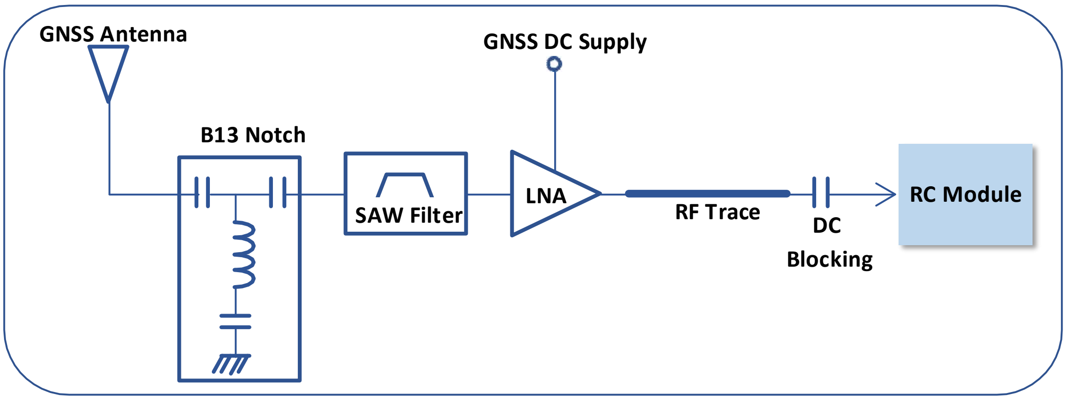

Figure 3. Basic active antenna lineup with B13 notch filter

8.5 RF Trace

The GNSS signal path from the RC module to the on-board antenna or the connector for the off-board antenna must be routed using an RF trace with a 50 Ohm characteristic impedance. The characteristic impedance depends on the printed circuit board dielectric, the RF trace width and the ground plane spacing.

A microstrip design is not desirable if the RF trace is fairly long (more than 3 cm). Instead, it is recommended to use coplanar stripline (i.e. embedded CPW) design. Such an RF trace works like a coaxial cable, trying to minimize the interference from the other RF or digital signals on the neighboring circuits, which could degrade the GNSS reception performance.

Figure 5 shows an example of a 50 Ohms coplanar stripline design for a host platform with a 1.6 mm four-layer PCB. The PCB stack up is also shown. The offset coplanar stripline is on layer-3 with reference to layer-2 and layer-4 as ground planes. The length of the stripline is 5 cm and the total insertion loss of the trace and the two end vias is approximately 0.5 dB in the GNSS frequency range.

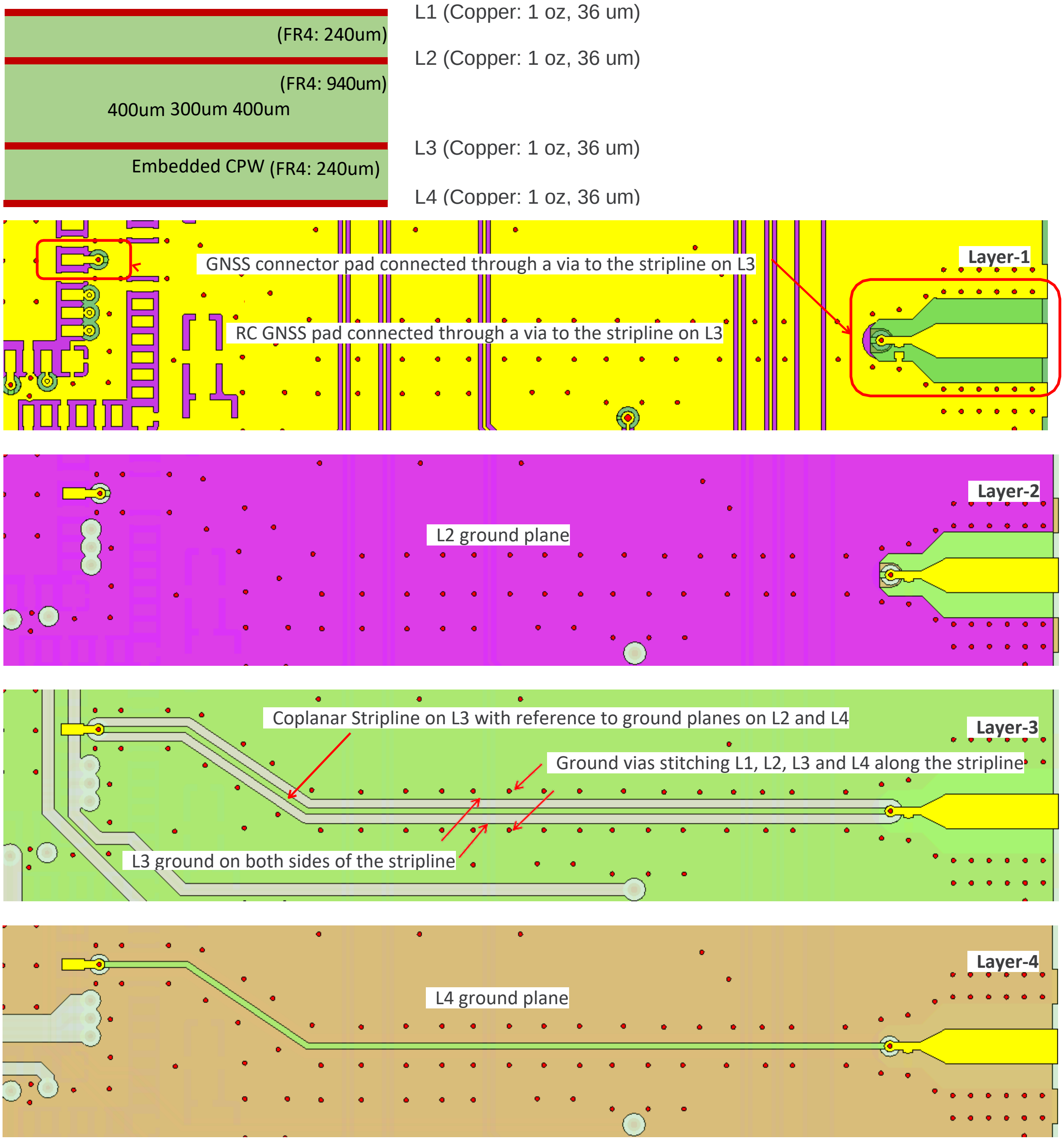

Figure 4. Sample coplanar stripline design for host platform with 1.6 mm 4-layer PCB

8.6 Coaxial Cable

Degradation in GNSS performance due to losses in the coaxial cable between the modem and the antenna is the main reason that an active antenna should be considered. The 50 Ohm coaxial cable should be good quality and double shielded to minimize the coupling of outside interference. If possible, a low-loss cable should be chosen which means using the largest-diameter cable that could physically work in the system. Also, it is recommended to minimize the number of connectors in the cable run to reduce issues that can arise due to reflections.

In addition to considering the RF loss of the cable, the DC resistance of the center conductor and the outer conductor (braid or solid shield) should be taken into consideration because the DC supply for the LNA uses these conducted paths, and the voltage at the active antenna should not drop below the minimum operating voltage of the LNA circuit in the active antenna.

Note that although the low-cost RG174/U coaxial cable is commonly used for active antennas, this cable is not double shielded.

8.7 Active Antenna Limitations with RC Modules

Based on the inherent limitations of the RC modules, the following table provides additional active GNSS specifications for optimum system performance.

Table 8: Active GNSS Antenna Specifications

Recommended Cascaded Noise Figure	Recommended Net Gain	Maximum Allowed Net Gain	Maximum Allowed GNSS signal level at RC input
< 2.5 dB	15 dB	17 dB	-110 dBm

Caution: *The signal power at the modem's GNSS connector must not exceed +10 dBm at any frequency for any amount of time, otherwise the modem may sustain permanent damage.*

9 Antenna to Antenna Isolation

To minimize interference of the host platform's transmitting antennas (e.g. WWAN, WLAN, etc.) on GNSS performance, make sure adequate separation is provided between the transmitting antenna(s) and the RC GNSS antenna.

The minimum required isolation is achieved by providing adequate separation between the antennas. Using different antenna polarizations can also improve antenna-to-antenna isolation.

The following table provides the minimum required isolation between the GNSS and WWAN/WLAN antennas:

Table 9: Minimum Antenna-to-Antenna Isolation

Module Series	WWAN – GNSS Isolation	WLAN – GNSS Isolation
RC76xx	> 15 dB in all WWAN uplink bands	> 15/20 dB in 2.4/5 GHz bands

10 Electrostatic Discharge

RC modules have internal ESD protection on the GNSS pin that meets the IEC-61000-4-2 standard (Electrostatic Discharge Immunity Test, ± 6kV Contact and ± 8kV Air).

Customers wanting to use an additional GNSS LNA circuit must consider extra ESD protection devices to protect the LNA circuit from the potential ESD damage.

Also, customers wanting to use an off-board active GNSS antenna must make sure the antenna or the platform is equipped with proper ESD protection against any strong electrostatic discharge that exceeds the IEC-61000-4-2 limits, otherwise the coaxial cable could carry the strong ESD to the platform and permanently damage the RC module.

11 Active GNSS Antenna Lineup Examples

Commercial off-the-shelf active GNSS antennas employ various designs. Customers must make the appropriate trade-offs based on the requirements of their overall GNSS application and the expected operating environment. There are other active antennas with different designs. Some commonly used lineups are shown in the following figures.

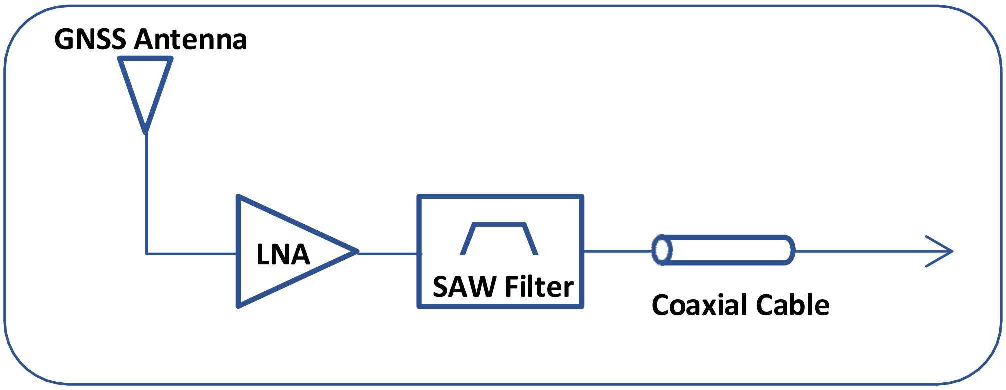

Figure 5. Active antenna lineup — Lower noise figure, susceptible to interference

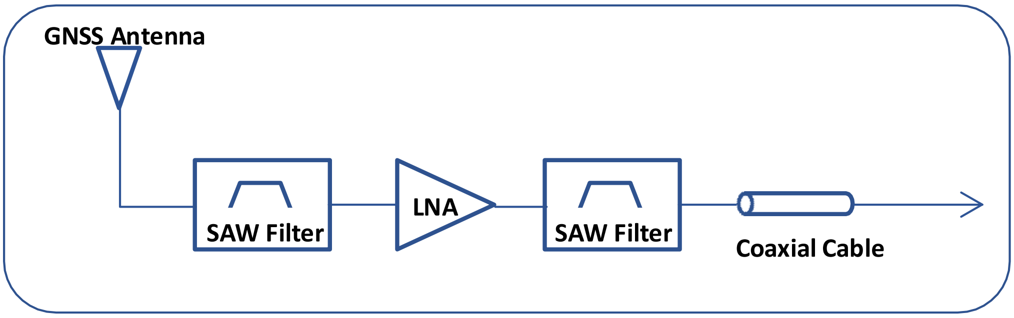

Figure 6. Active antenna lineup — Distributed filtering (moderate noise figure, high interference rejection)

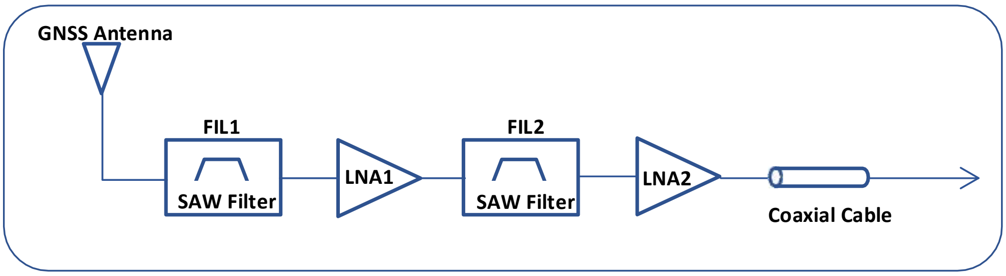

Figure 7. Active antenna lineup — Distributed filtering and distributed amplification

The lineup illustrated in Figure 7 utilizes both distributed filtering and distributed amplification. Each component of this lineup is described below to illustrate some of the important design considerations.

- FIL1 –The first filter is chosen for low insertion loss and thus typically has less rejection. It is used to attenuate strong out-of-band signals that may otherwise drive the LNA(s) into compression. It is also used to attenuate signals at half the GNSS frequency that could generate second harmonics in the GNSS band due to the nonlinearities in the LNA(s). This filter should also have high linearity so as not to create its own intermodulation products.
- LNA1 – The first LNA is chosen for low noise figure to minimize the cascaded noise figure of the complete lineup. It is also chosen for high linearity to minimize the chance of compression from strong out-of-band signals and minimize generation of intermodulation products that could desensitize the GNSS receiver.
- FIL2 – The second filter is chosen for high out-of-band rejection. Low insertion loss is preferred but is not critical because the cascaded noise figure for the whole lineup is dominated by the first filter and the first LNA.
- LNA2 – The second LNA is optional and is chosen for added gain, if necessary, typically for an active antenna with a long coaxial cable. Linearity is still an important consideration because the signal level is higher for LNA2 than for LNA1. Noise figure is not critical because the cascaded noise figure for the whole lineup is dominated by the first filter and the first LNA.
- COAX – The RF coaxial cable is chosen for best shielding and reasonably low loss. Minimizing the cable loss is not critical as long as the LNA(s) can compensate for it. However, minimizing the number of connectors in the cable run is recommended to reduce issues that can arise due to reflections.

12 Reference Documents

	Filename	Comment
[1]	AirPrime RC76xx Product Technical Specification	Document # 41113440

13 Support

For direct clients: contact your Sierra Wireless FAE

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14 Document History

Level	Date	History
1.0	April 13, 2020	Creation
2.0	October 05, 2020	Added QZSS system Added support for RC7630

15 Legal Notice

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