GNSS Antenna Application Note

GNSS Module Series

Version: 1.0

Date: 2024-03-28

Status: Released

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	Ensure that the product may be used in the country and the required environment, as well as that it conforms to the local safety and environmental regulations.
	Keep away from explosive and flammable materials. The use of electronic products in extreme power supply conditions and locations with potentially explosive atmospheres may cause fire and explosion accidents.
	The product must be powered by a stable voltage source, and the wiring shall conform to security precautions and fire prevention regulations.
	Proper ESD handling procedures must be followed throughout the mounting, handling and operation of any devices and equipment that incorporate the module to avoid ESD damages.

About the Document

Document Information	
Title	**GNSS Antenna Application Note**
Subtitle	GNSS Module Series
Document Type	Application Note
Document Status	Released

Revision History

Version	Date	Description
-	2023-06-21	Creation of the document
1.0	2024-03-28	First official release

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1 Product Description

Quectel GNSS modules are applied to the products from various industries around the world. Due to the differing application scenarios, the selection and application of the GNSS antenna needs to be evaluated depending on the specific product requirements. This document aims to introduce main parameters of GNSS antenna and list some details to be considered when selecting and incorporating a GNSS antenna into a new design.

2 GNSS Antenna Basics

GNSS signals become extremely weak when they reach the Earth's surface and often fall below the thermal noise floor of GNSS receivers. Thus, the selection of an appropriate GNSS antenna is crucial for optimal system performance. A high-quality GNSS antenna can enhance the carrier-to-noise ratio (C/N_0) and enable reception of a greater number of satellites.

2.1. Passive vs. Active Antenna

The passive antenna usually contains only the radiating element and does not require a power supply to function. On the other hand, the active antenna includes additional components such as LNA, SAW Filter and associated components like Diplexers mounted close to the base and feed point of the passive radiator. The LNA (Low Noise Amplifier) requires a power source usually fed on the centre line of the Co-axial cable and helps to reduce the overall noise figure of the system, improving C/N_0 and sensitivity, especially in scenarios where there is a significant loss between antenna and the module. The figure below illustrates the frameworks of a passive and an active antenna.

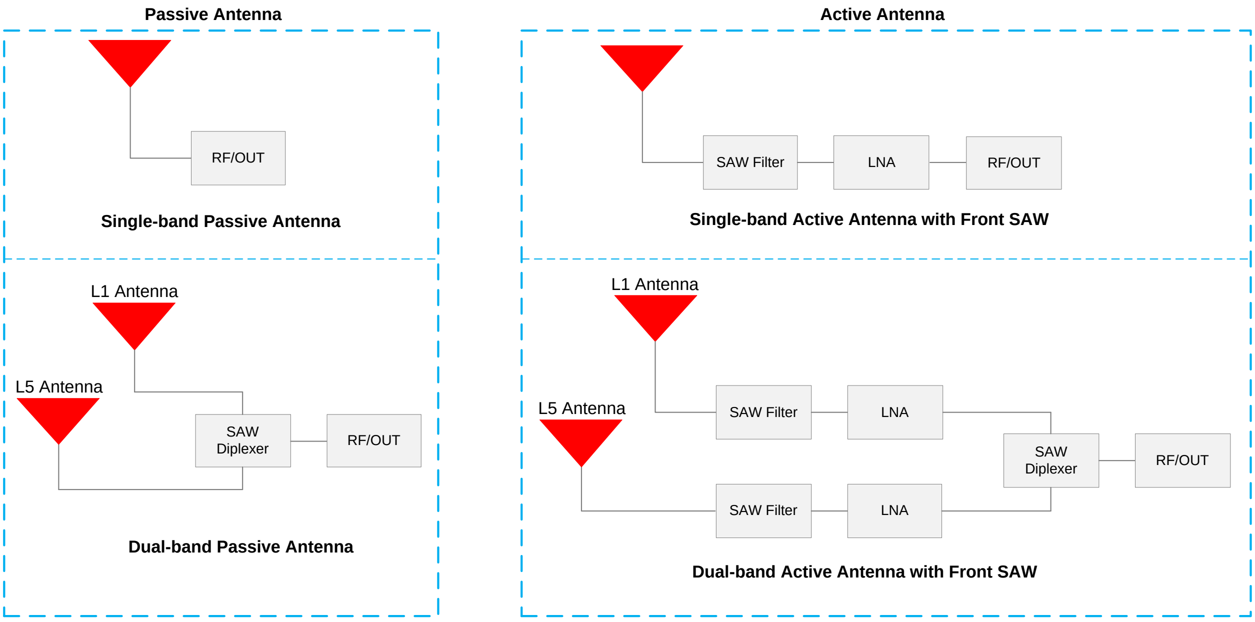


Figure 1: Frameworks of Passive and Active Antenna

C/N_0 is an important factor for GNSS receivers, and it is defined as the ratio of the received modulated carrier signal power to the received noise power in one Hz bandwidth.

C/N_0 formula:

$$C/N_0 = \text{Power of GNSS signal} - \text{Thermal Noise} - \text{System NF(dB-Hz)}$$

The "Power of GNSS signal" is GNSS signal level. In practical environment, the signal level at the earth's surface is about -130 dBm. "Thermal Noise" is -174 dBm/Hz at 290 K. To improve C/N_0 of GNSS signal, an LNA could be added to reduce "System NF".

"System NF", formula:

$$\text{NF} = 10 \log \text{F (dB)}$$

"F" is the noise figure of receiver system:

$$\text{F} = \text{F1} + (\text{F2} - 1)/\text{G1} + (\text{F3} - 1)/(\text{G1} \cdot \text{G2}) + \cdots$$

"F1" is the first stage noise figure; "G1" is the first stage gain, etc. This formula indicates that the LNA with enough gain can compensate for the noise figure behind the LNA. In this case, "System NF" depends mainly on the noise figure of components and traces before the first stage LNA plus noise figure of the LNA itself. This explains the need for using an active antenna if the antenna connection cable is too long.

However, excessive gain in the LNA may cause saturation or system de-sensitization. It should be noted that different modules have specific total gain requirements. For active antennas, you should refer to the hardware design document for the recommended gain values. The total antenna gain equals the internal LNA gain minus the total insertion loss of cables and components inside the antenna. Additionally, powering the LNA inside the active antenna increases the system power consumption. In addition, it is necessary to ensure that it operates within the specified voltage range.

To improve anti-interference capability, most active antennas incorporate a SAW filter to block strong out-of-band signals, such as those transmitted by the LTE. In a complex communication system, the LNA can generate intermodulation signals within the desired frequency band. By placing a SAW filter before the LNA, the power of out-of-band signals is attenuated, thereby reducing the power of intermodulation products. This helps to mitigate interference and maintain the overall signal quality.

2.2. Main Parameters of GNSS Antennas

Basically, the main parameters of GNSS antennas include operation frequency band, total radiation efficiency, gain, radiation pattern, axial ratio, beamwidth, and phase center stability.

Recommended values are listed for each parameter in the hardware design document. However, please note that these values are not mandatory requirements. The suitability of the antenna for your specific needs should be assessed through practical testing to ensure it meets the desired performance criteria.

2.2.1. Operation Frequency Band

The operation frequency of a GNSS antenna is typically defined as the frequency range in which the Voltage Standing Wave Ratio (VSWR) is below 2.5. GNSS antenna must be functional within the required GNSS bands. The following frequency bands and central frequencies of GNSS constellations should be considered when selecting an appropriate antenna.

Table 1: GNSS Frequency Bands and Central Frequency (Unit: MHz)

Constellation	GNSS Frequency Band and Central Frequency (Unit: MHz)					
GPS	L1: 1575.42	L2C: 1227.6	L5: 1176.45	-	-	-
GLONASS	L1: 1602	L2: 1246	L3: 1202.025	-	-	-
Galileo	E1: 1575.42	E5a: 1176.45	E5b: 1207.14	E6: 1278.75	-	-
BDS	B1I: 1561.098	B1C: 1575.42	B2a: 1176.45	B2b: 1207.14	B2I: 1207.14	B3I: 1268.52
QZSS	L1: 1575.42	L2C: 1227.6	L5: 1176.45	L6: 1278.75	-	-
NavIC	L5: 1176.45	-	-	-	-	-
L band	1525-1559	-	-	-	-	-

2.2.2. Total Radiation Efficiency

Radiation efficiency is the ratio of the total power radiated by an antenna to the net power accepted by the antenna. When energy is fed to the antenna connector, some energy will be reflected and lost because of the impedance mismatch. Total radiation efficiency is the ratio of the total power radiated by an antenna to the power fed to the antenna connector.

For example, if the power fed to the antenna connector is 100, 10 is reflected at the antenna connector and the final radiated power is 50. Then, the net power is 90, the radiation efficiency is 50 / 90 and the total radiation efficiency is 50 / 100.

Total radiation efficiency is measured in a standard microwave anechoic chamber and is influenced by factors such as structure and material of radiator patch, size of ground plane, and surrounding environment. These factors are complex and need to be evaluated by antenna manufacturers.

Antenna total radiation efficiency impacts the C/N_0 of the receiver, which in turn affects the positioning accuracy. Typically, for ceramic patch antennas on GNSS L1, total radiation efficiency of over 60 % can be achieved on a 25 mm × 25 mm size or 40 % on an 18 mm × 18 mm size.

2.2.3. Gain

Passive antenna gain is defined as the ratio of the radiation intensity in a given direction to the radiation intensity that would be produced if the power accepted by the antenna were isotropically radiated. It represents the antenna's ability to transmit and receive signals in a specific direction. The gain of the antenna can affect the C/N_0 of the receiver.

The gain of a passive antenna is commonly expressed in two units: dBi and dBd. The dBi unit is based on the reference of an ideal omnidirectional point source antenna, while the dBd unit is based on the reference of a dipole antenna. The conversion between the two units is as follows: 0 dBd = 2.15 dBi.

For active antenna, it is important to mention the gain of internal LNA. The LNA gain is defined as the ratio of the output power to the input power, and it is typically expressed in dB.

2.2.4. Radiation Pattern and Beamwidth

GNSS antennas should have a low level of directivity to cover a wide area of the sky and receive signals from multiple satellites. The following figure illustrates the radiation pattern of an L5 chip antenna. An omnidirectional pattern, which provides equal coverage in all directions, is preferred for better robustness and signal reception.

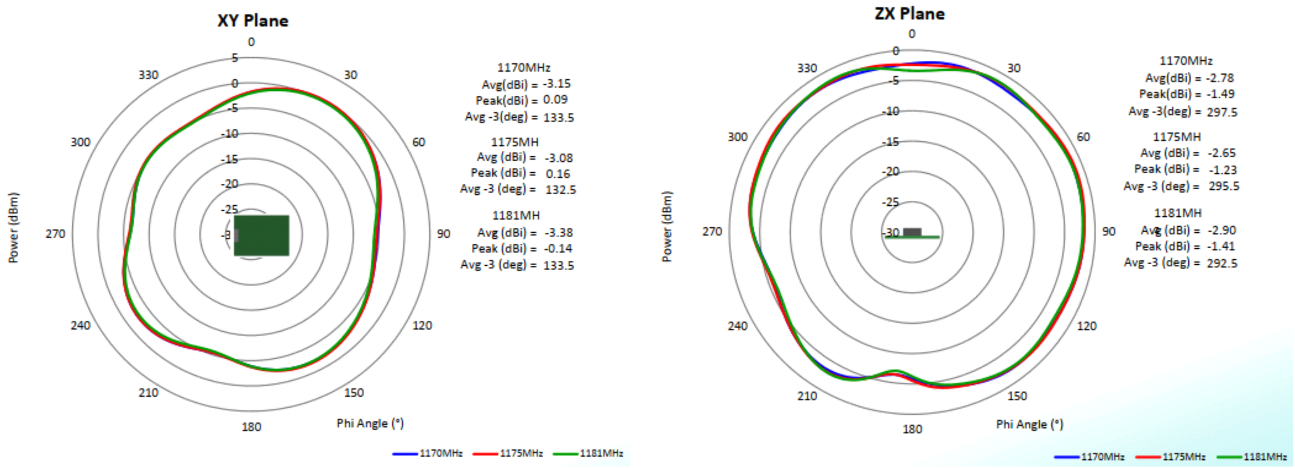


Figure 2: Radiation Pattern of L5 Chip Antenna

Beamwidth is an important parameter in the radiation pattern of an antenna. We often use the half-power beamwidth (HPBW) to indicate how well a directional antenna, such as a ceramic patch antenna, can receive satellite signals at different elevations. HPBW refers to the angle between the two directions in which the radiation intensity is one-half the maximum value in a radiation-pattern cut containing the direction of the maximum of a lobe. It is generally recommended to have an HPBW between 90° and 120°. If the beamwidth is too large, it may lead to a deterioration of multipath rejection.

Radiation pattern and beamwidth of the antenna directly impact the number of satellites visible to the receiver, thereby affecting the positioning accuracy.

2.2.5. Polarization and Axial Ratio

GNSS signals are right-hand circular polarized, and if a linear polarized antenna is used, there will be about 3 dB attenuation due to polarization loss when receiving GNSS signals.

Axial ratio measures the purity of circular polarization of an antenna. It varies with the elevation angle, and at the zenith, the axial ratio can be less than 1 dB for a well-designed circular polarized antenna. However, it is difficult to maintain a good axial ratio at low elevations. Usually, it is recommended to have an axial ratio below 3 dB at the zenith within the operation bandwidth. The axial ratio of the antenna can affect the C/N_0 of the receiver.

Right-hand circular polarized antennas can only receive right-hand circular polarized waves and cannot receive left hand circular polarized waves. When a right hand circular polarized wave encounters a symmetrical target, such as a plane or a sphere, the reflected wave transforms into a left-hand circular polarized wave. Leveraging the property, using the right hand circular polarized antenna can mitigate the multipath effect.

2.2.6. Phase Center Stability

The phase center stability of the antenna can affect the positioning accuracy of the receiver. In situations requiring a high level positioning accuracy, such as centimeter level, phase center stability could be a critical factor.

Once the electromagnetic wave radiated by the antenna travels a certain distance, its phase surface is approximated as a spherical surface, and the center of the sphere is considered the equivalent phase center of the antenna. The phase center is described as the geometric point where all electromagnetic waves either converge or emanate from. In the GNSS measurement process, the obtained position observations are based on the GNSS antenna phase center position. The phase center usually is not where the physical center is. As a result, the final positioning accuracy could be influenced by this tiny error.

The figure below illustrates the phase center offset and phase center variation. For centimeter level positioning application, phase center offset and phase center variation should be below 20 mm.

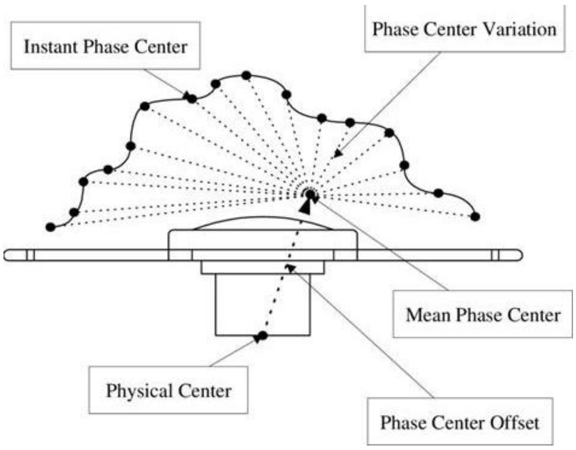


Figure 3: Physical Center vs. Phase Center

2.3. Antenna Types and Characteristics

2.3.1. Ceramic Patch Antenna

Ceramic patch antenna is the most common type for GNSS application due to its superior RHCP performance, higher total radiation efficiency and low cost.

The figures below illustrate the radiation pattern of a ceramic patch antenna with the maximum gain at the upward direction and very weak backward radiation.

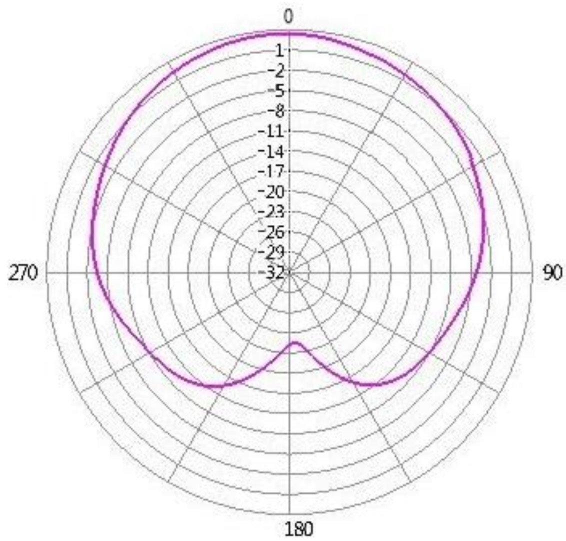


Figure 4: 2D Radiation Pattern of Ceramic Patch Antenna

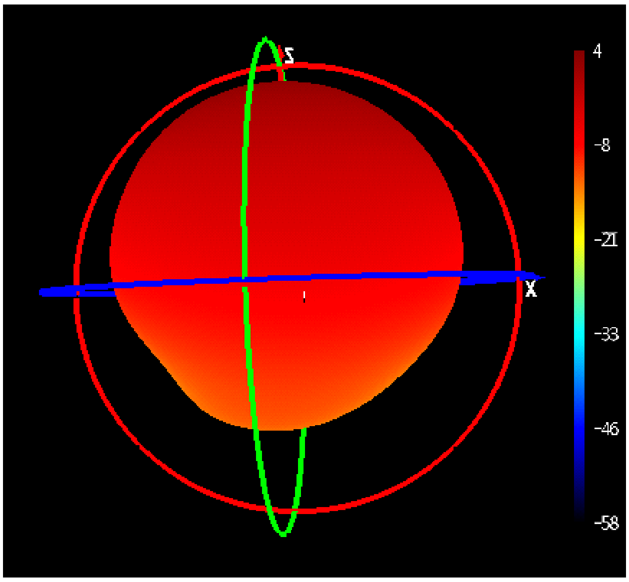


Figure 5: 3D Radiation Pattern of Ceramic Patch Antenna

Antenna performance is closely linked to the size of the antenna and the dimensions of the ground plane. The total radiation efficiency of a ceramic antenna measuring 25 mm × 25 mm × 4 mm over a 70 mm × 70 mm board can easily reach up to 70 %.

Ceramic patch antennas come in various sizes, ranging from 10 mm × 10 mm to 36 mm × 36 mm, which facilitates their integration into numerous GNSS devices. However, patches smaller than 18 mm × 18 mm are not recommended as their performance may not be guaranteed.

2.3.2. Helix Antenna

A helix antenna is an antenna consisting of one or more conductive wires wound in the form of a helix. The most common type is the quadrifilar helix antenna. Compared to the ceramic patch antenna, the helix antenna offers improved half-power beamwidth (HPBW). The length of each wire in the helix should be a quarter signal wavelength or an integral multiple thereof if the helix is filled with air. The size of the antenna can be reduced by printing helix arms on high dielectric constant ceramic substrate.

Figure 6: GNSS Quadrifilar Helix Antenna

The figures below illustrate the radiation pattern of a helix antenna with superior half-power beamwidth (HPBW), the maximum gain at upward direction and very weak backward radiation.

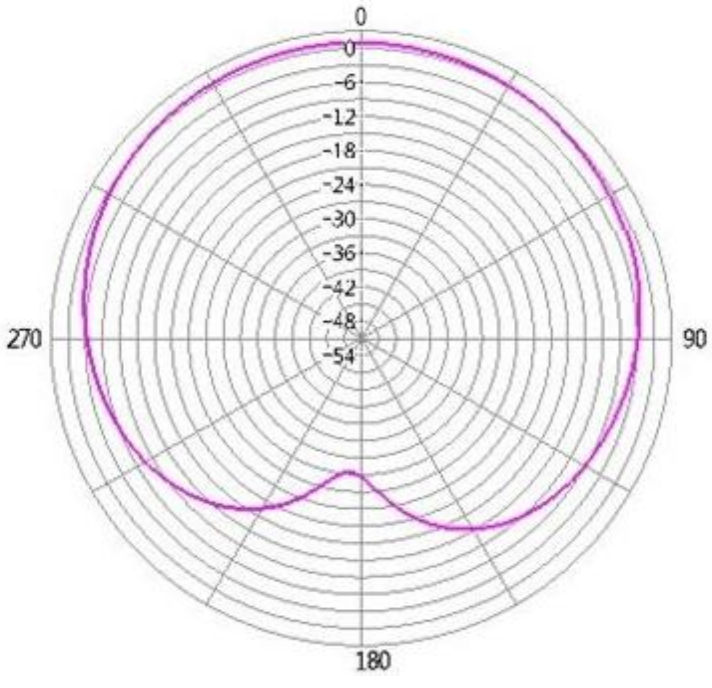


Figure 7: 2D Radiation Pattern of Helix Antenna

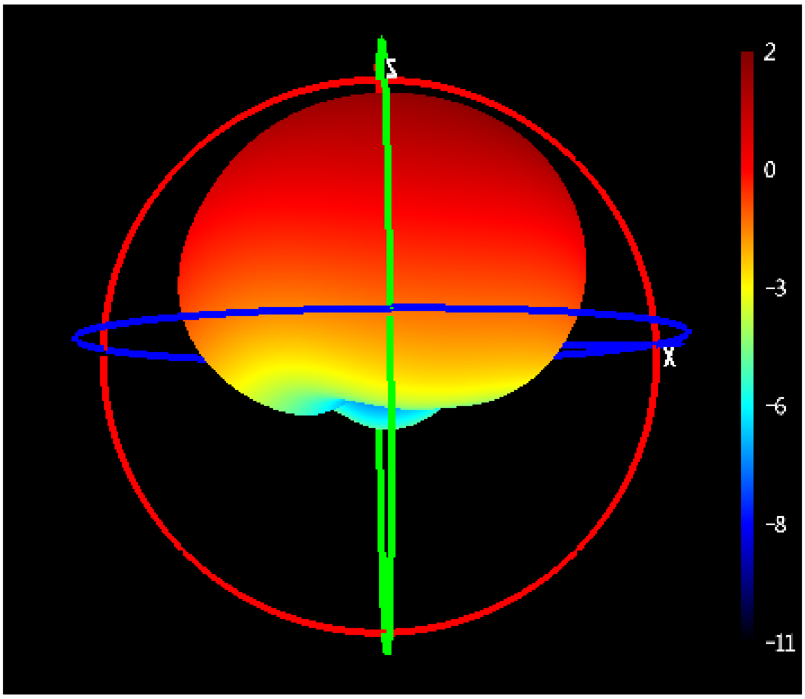


Figure 8: 3D Radiation Pattern of Helix Antenna

2.3.3. Chip Antenna

Due to their compact size, chip antennas are suitable for applications with limited space. The chip antenna is illustrated below.

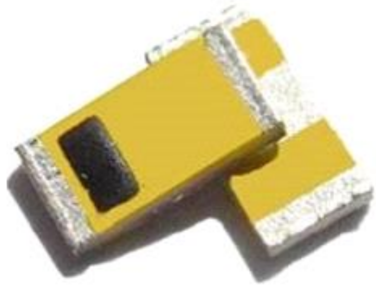


Figure 9: Chip Antenna

Chip antennas require clearance on the PCB for optimal bandwidth and total radiation efficiency. However, they may experience polarization loss when receiving GNSS signals due to their linear polarization characteristic. Additionally, the antennas have strict requirements for SMD positioning on the PCB, the size of the keepout area and the surrounding environment. Usually, the antenna manufacturers evaluate and optimize the PCB and overall device structure to minimize frequency offset and interference. The compact size of chip antennas makes them a suitable option in case of limited space on the circuit board.

2.3.4. Planar Inverted F-shaped Antenna

The figure below illustrates a typical structure of a Planar Inverted F-shaped Antenna (PIFA). The right view of the entire antenna is like an inverted English letter F. PIFA is commonly utilized in handheld devices since it's easy to integrate into small devices. PIFA has wider bandwidth than the chip antenna and exhibits an omni-directional pattern. However, the distance from the top patch to ground plane is often the factor restricting the performance of the antenna.

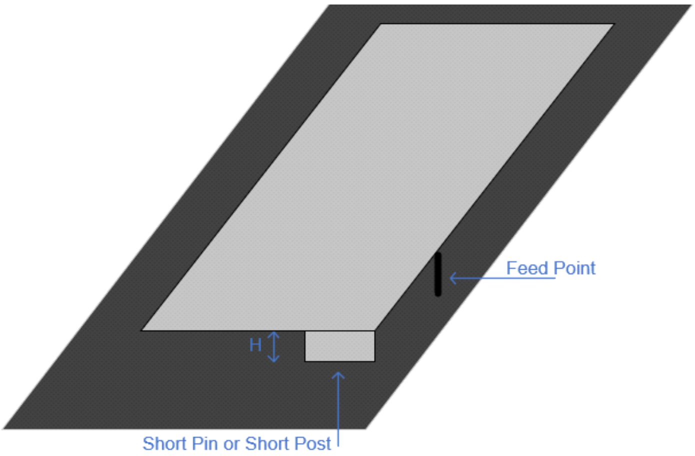


Figure 10: Typical Structure of PIFA

The PIFA installed on the plastic shell can be used in case of limited space on the circuit board of the equipment. However, its linear polarization characteristic can result in polarization loss when receiving RHCP GNSS signals. When using PIFA, thorough evaluation by antenna manufacturers is necessary to achieve optimal performance due to its sensitivity to the surrounding environment.

3 Choosing Optimal Antenna for Practical Application

3.1. Active or Passive Antenna

When the RF line between the antenna and the module is relatively long, for instance, when the RF line is longer than 1 m or the loss exceeds 1 dB, it is recommended to use the active antenna. In addition, active antenna is often used in modules with relatively high noise figures, like LG69T series. However, for modules with internal LNA as the first stage, like LC79H, the use of an active antenna may not necessarily result in superior C/N_0 compared to a passive antenna.

3.2. Ceramic Patch Antenna or Helix Antenna

The ceramic patch antenna is widely favored in mounting on a flat surface, as it achieves a small size and cost-effectiveness while maintaining good gain, total radiation efficiency, and axial ratio. However, the ceramic patch antenna must point to the sky to receive as many satellites as possible, which is a challenge for applications in handheld devices. Antenna performance is tightly related to the size of antenna and the ground plane.

The helix antenna achieves a good axial ratio and exhibits an omnidirectional radiation pattern in the horizontal direction even without a ground plane. Although usually taller and more expensive than a ceramic patch antenna, a helix antenna can provide a good and robust receiving performance in environments where a ground plane cannot be provided, which makes it particularly suitable for operation environments where a ground plane cannot be provided. However, keep in mind that the axial ratio of a helix antenna will deteriorate when it is mounted on a metal surface.

3.3. Chip Antenna or PIFA

Chip antenna and PIFA are also acceptable in some specific applications such as wearable devices, and mobile phones. These devices usually have very limited internal space and require omni-directional pattern.

When the circuit board space of the equipment is limited, an extremely small chip antenna is a good choice. The PIFA antenna installed on the plastic shell can be used when there is no space for the antenna on the circuit board of the equipment. However, their linear polarization characteristic will cause polarization loss when receiving RHCP GNSS signal. When using the two types of antennas, the antenna manufacturers must conduct a comprehensive evaluation to achieve the best performance due to their excessive sensitivity to the surrounding environment.

3.4. Suggestions for Antenna Parameters in RTK Application

For RTK application scenarios, it is recommended that the antenna parameters meet the following requirements.

Table 2: Suggestions for Antenna Parameters in RTK Application

Antenna Parameter		Requirement
Polarization		RHCP
Gain		≥ 3 dBi (Zenith)
VSWR		≤ 2
Axial Ratio	Elevation 90°	≤ 3 dB
	Elevation 60°	≤ 6 dB
Total radiation efficiency		> 60 %
Phase Center Offset (PCO)		≤ 20 mm
Phase Center Variation (PCV)		≤ 20 mm
Feed Points [1]		Dual feed or quadruple feed
Antenna Size [1]		Double layer ceramic patch structure: Lower ceramic patch: ≥ 35 mm × 35 mm × 4 mm Upper ceramic patch ≥ 25 mm × 25 mm × 4 mm

[1] The recommended requirements should be met if a ceramic patch antenna is used.

4 Antenna Design Considerations

Due to the potential impact of the device shell and internal components on antenna performance, the antenna design and modifications must be carried out considering the overall state of the device.

4.1. Design Requirements for Active and Passive Antennas

Based on the selected GNSS module and application scenario, after deciding whether to use an active or a passive antenna, you should consider the following design requirements.

- If you opt for an active antenna, to further mitigate the impact of out-of-band signals on the GNSS module performance, you must choose the active antenna whose SAW filter is placed in front of the LNA in the internal framework. DO NOT place the LNA in the front.
- If you opt for a passive antenna in a complex electromagnetic environment, you must add a SAW filter circuit to the antenna design to further mitigate the impact of out-of-band signals on the GNSS module, as specified in the hardware design document. In the actual layout, the circuit should be placed close to RF_IN pin.
- If you opt for a passive antenna with an added LNA circuit between the antenna and the GNSS module, you must add a band-pass filter circuit in front of the LNA.

4.2. Ceramic Patch Antenna

When using a ceramic patch antenna, pay attention to the ground plane, position on the PCB, orientation and surrounding environment of the antenna. These four aspects affect the performance of the ceramic patch antenna. Please contact the antenna manufacturer for a full evaluation to achieve the best performance.

4.2.1. Ground Plane

The size of the ground plane will affect parameters such as the central frequency and gain of the ceramic patch antenna.

The figure below illustrates a ceramic patch antenna on the 30 mm × 30 mm ground plane with 1575.42 MHz center frequency.

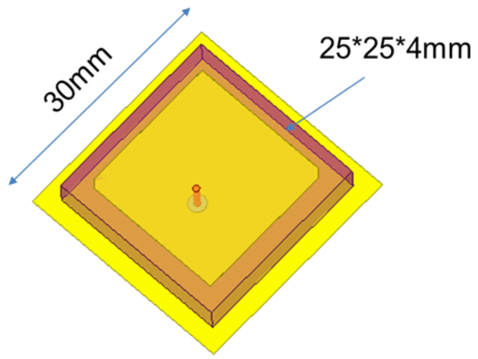


Figure 11: Ceramic Patch Antenna on 30*30 mm Ground Plane

If you increase the size of the ground plane while keeping the ceramic antenna unchanged, the center frequency of the antenna will shift to the higher frequency illustrated below.

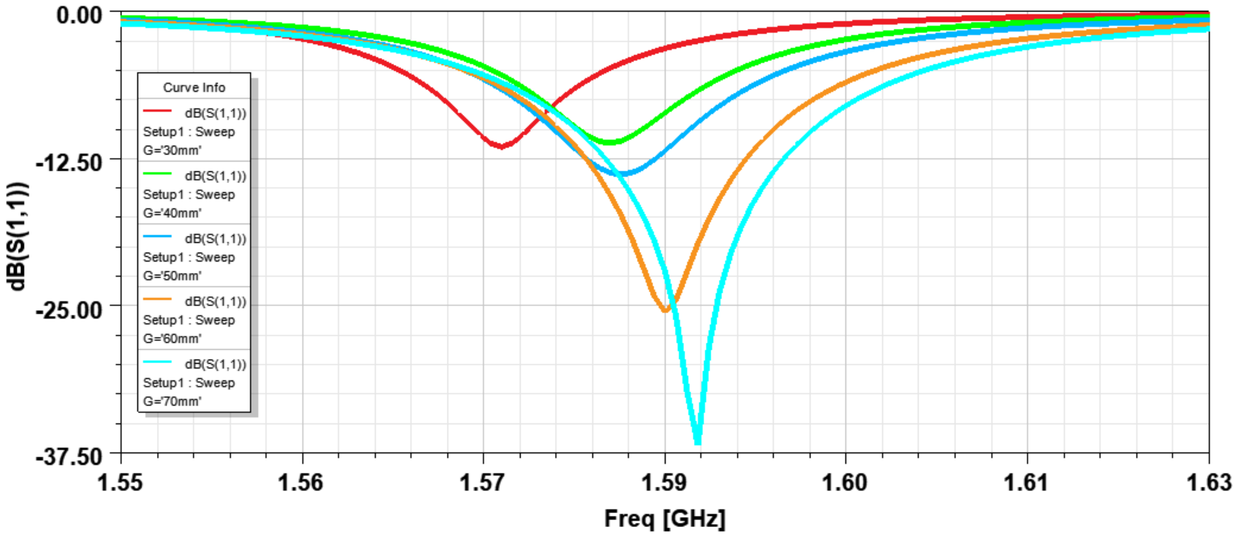


Figure 12: Center Frequency Variation with Different Ground Plane Sizes

Keep the size of the ceramic antenna constant, and increase the size of the ground plane in the range from 30 mm × 30 mm to 110 mm ×110 mm, the gain of the antenna initially decreases, then increases, and then decreases as the size of the ground plane increases, as illustrated in the following figure.

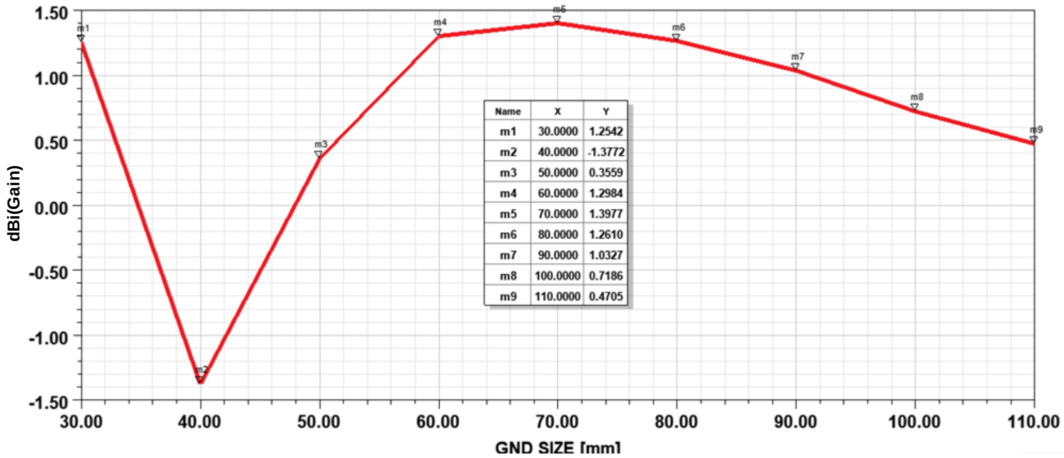


Figure 13: Gain with Different Ground Plane Sizes

4.2.2. Antenna Position on PCB

The position of the antenna affects parameters such as the VSWR and gain of the ceramic patch antenna.

Common positions are illustrated below (A: PCB center, B: PCB corner, C: PCB edge middle).

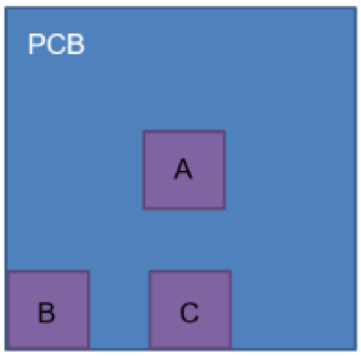


Figure 14: Different Antenna Positions (A, B, C)

For some antennas, the VSWR and gain can be optimal when placed in position A. However, some antennas can achieve optimal performance when placed in position B or position C. It is recommended to contact the antenna manufacturer for evaluation and simulation to select the best placement when designing a product.

4.2.3. Antenna Orientation and Surrounding Environment

The radiation characteristics of the ceramic patch antenna also depend on the orientation of the antenna and the surrounding environment, for example, metal devices near the antenna. When designing, it is recommended to follow the rules below:

- Make sure the antenna is pointing to the sky. If the antenna is tilted, in some scenarios, even if the satellite search and C/N_0 are very good, the positioning accuracy of the module may be poor due to the multipath effect.
- Maintain at least 10 mm distance between the patch antenna and other tall metal components to prevent adverse impacts on antenna performance.

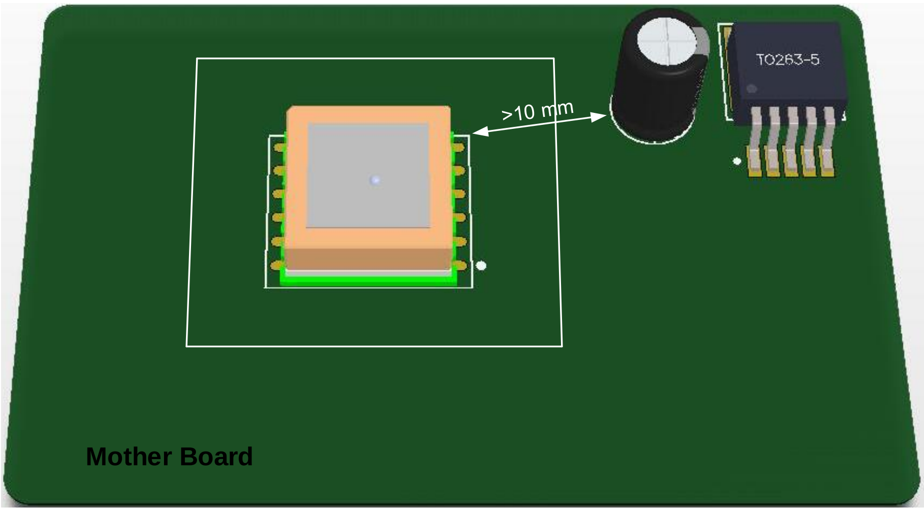


Figure 15: Recommended Distance Between Module and Tall Metal Components

- Device enclosure should be made of non-metal materials, particularly in the vicinity of the antenna area. The minimum distance between antenna and enclosure is 3 mm.

4.2.4. Feed Points of Ceramic Patch Antenna

Common ceramic antennas come in three types of feed configurations: single feed, dual feed, and quadruple feed:

- **Single feed ceramic antennas** are often used as single-band antennas with only one feed pin.
- **Dual feed ceramic antennas** are commonly used as dual-band antennas. One feed pin is connected to the high frequency part, while the other feed pin is connected to the low frequency part.
- **Quadruple feed ceramic antennas** are often used in high-precision positioning applications. Two feed pins are connected to the high-frequency part, and the other two feed pins are connected to the low-frequency part. The quadruple feed ceramic antennas can achieve better axial ratio and phase center stability, thereby improving the positioning accuracy of the module.

4.3. Helix Antenna

Helix antennas can deliver a reliable and robust receiving performance in environments where a ground plane is not available. However, keep in mind that the axial ratio of a helix antenna deteriorates when it is mounted on a metal surface. A comparison between figures shown below reveals a significant degradation in the axial ratio at 1575 MHz (indicted by the white line) when the helix antenna is positioned on a 30 cm × 30 cm metal plate.

When installing the helix antenna above the metal plane, the product layout must strictly adhere to the requirements of the antenna manufacturer.

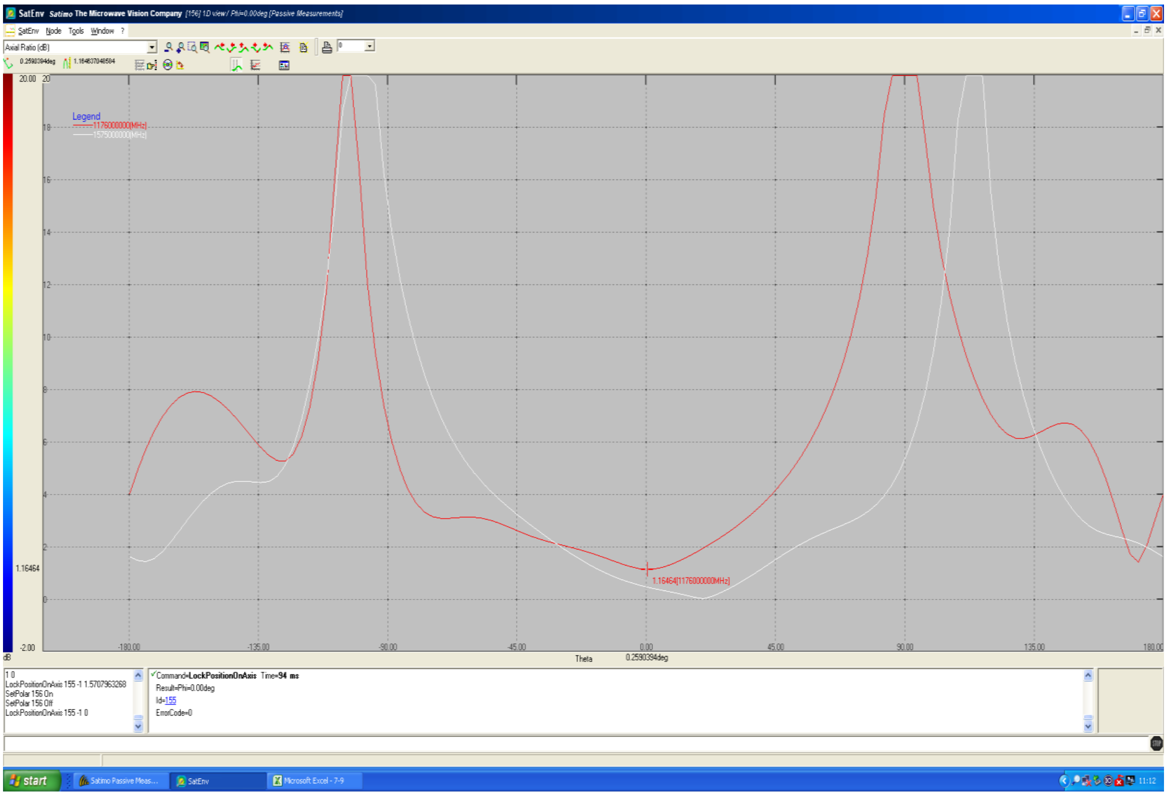


Figure 16: Axial Ratio of Helix Antenna in Free Space

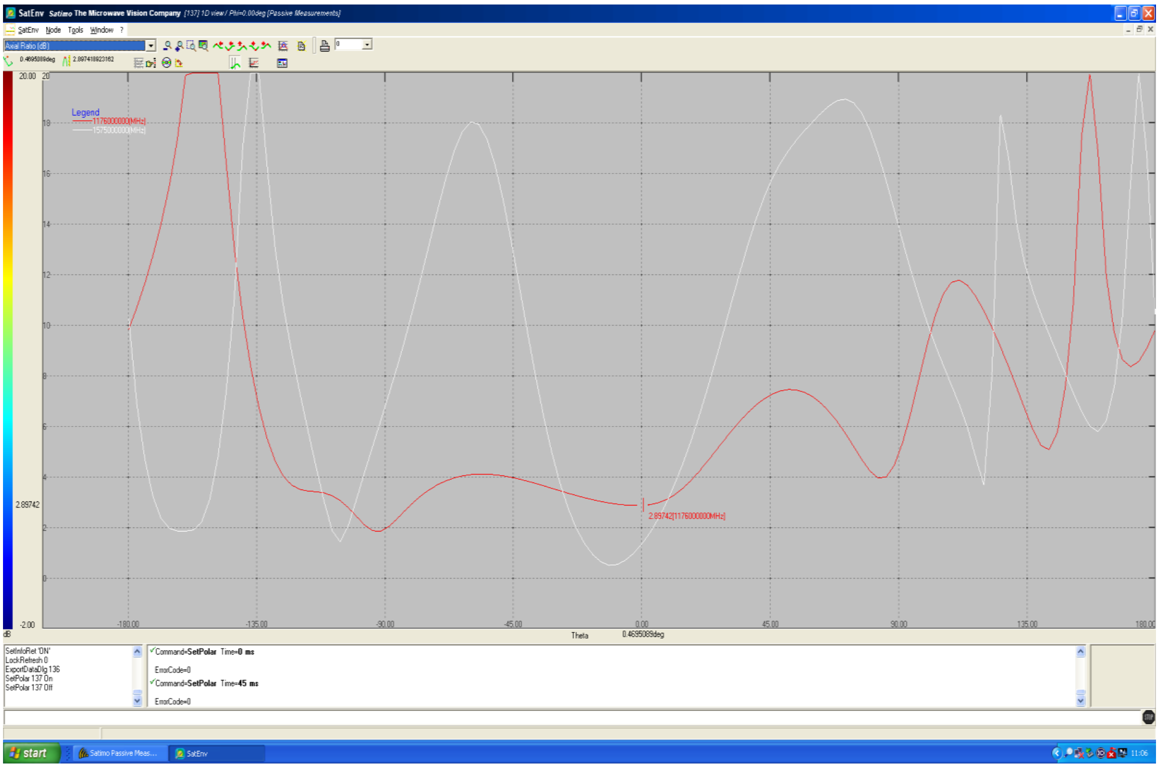


Figure 17: Axial Ratio of Helix Antenna on 30 cm × 30 cm Metal Plate

4.4. Chip Antenna and PIFA

The chip antenna and PIFA are good choices for devices with severe internal space constraints. However, these two antennas impose strict requirements on PCB positioning, keepout area dimensions, and the surrounding environment.

Please note that when the RF input pin of the module is electric, the PIFA cannot be connected to the module directly because of the short pin inside the PIFA, and a DC block capacitor must be added.

The following figure illustrates a chip antenna (model YC0013AA) from Quectel. The antenna specification has clear requirements for the circuit board size, antenna position, and keepout area.

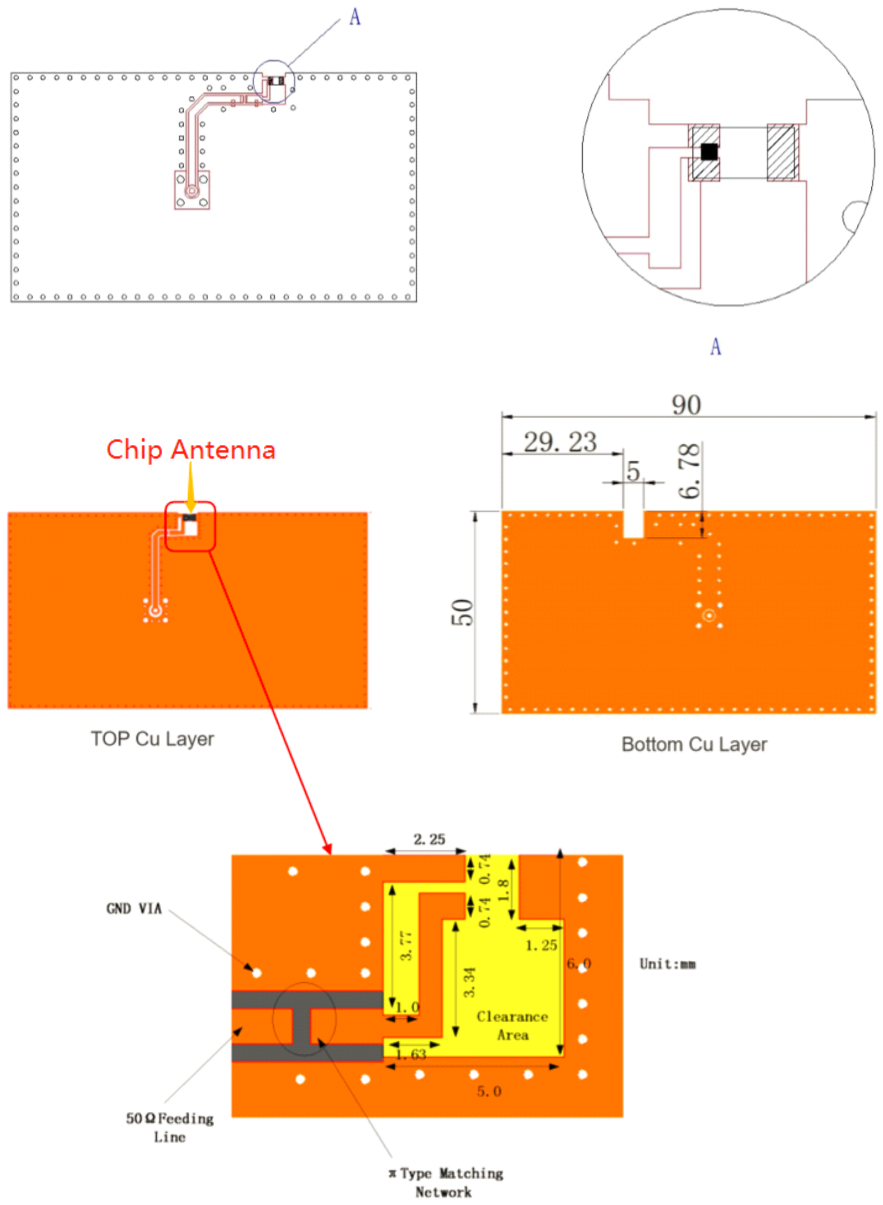


Figure 18: Reference PCB Design of Chip Antenna YC0013AA (Unit: mm)

4.5. Antenna Matching and ESD Issues

When designing the circuit board, you should consider the antenna matching and ESD issues. It is recommended to design the PCB according to the figure below.

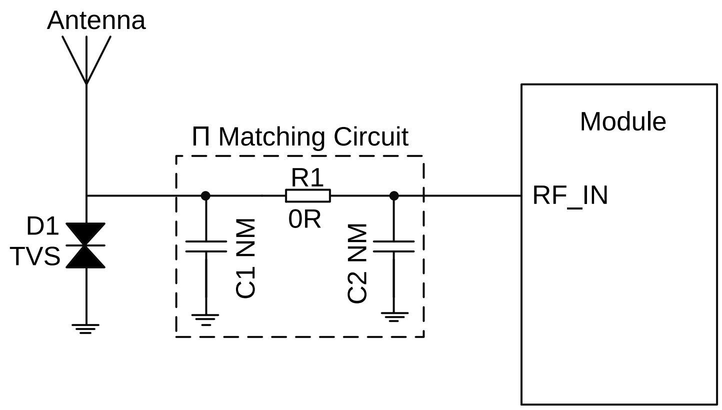


Figure 19: Antenna Reference Design

The C1, R1, and C2 components are reserved for matching antenna impedance. By default, R1 is 0 Ω, and C1 and C2 are not mounted. D1 is an ESD protection device to protect the RF signal input from the potential damage caused by ESD. The junction capacitance of D1 cannot exceed 0.6 pF and a transient voltage suppressor is recommended. The impedance of the RF trace line on the main PCB should be controlled to 50 Ω, and the trace length should be kept as short as possible.

4.6. Dual Antenna System

In different application scenarios, a product may require the supporting of both the embedded antenna and the external active antenna. For example, in an open environment, the product uses the embedded antenna, while in an environment with obstructions, the product switches to the external active antenna. The active antenna is positioned in a location that ensures a stronger signal through the RF coaxial cable. In such cases, the two antennas need to facilitate automatic switching for convenient installation and usage.

The following figure is a block diagram of the dual antenna system with automatic switching functionality. This system incorporates an RF single pole double throw switch (SPDT) to select the RF path and determine the antenna through which the GNSS signal is directed to the GNSS module.

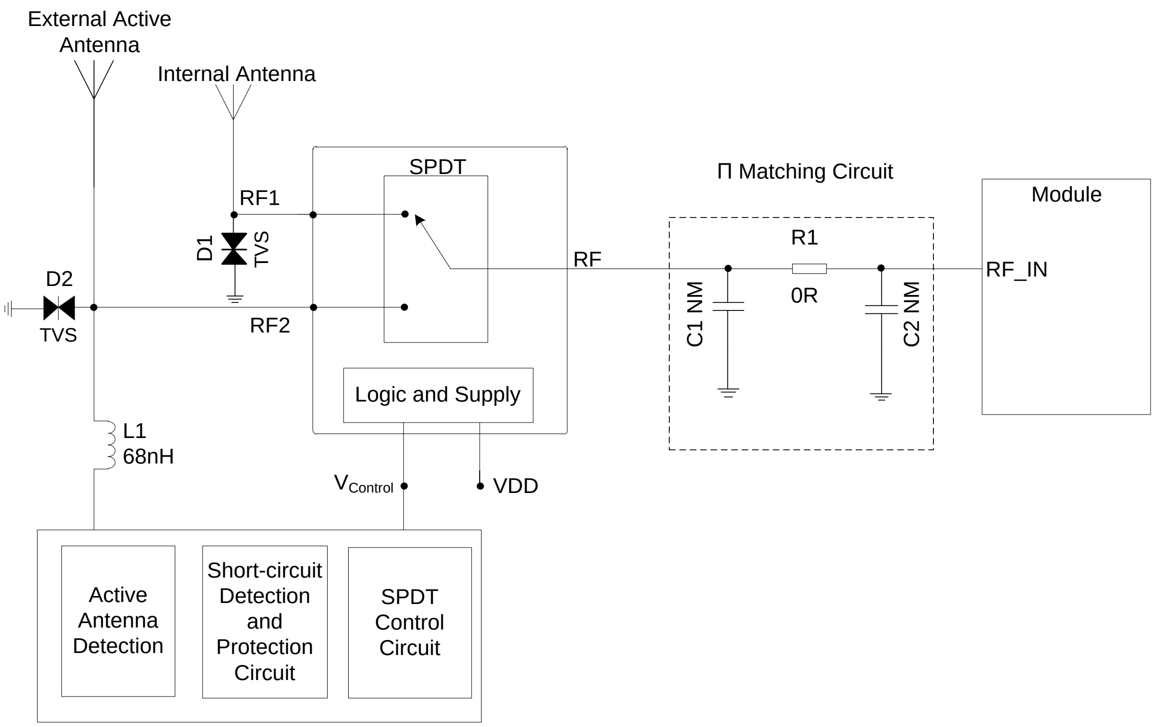


Figure 20: Dual Antenna System

When using a dual antenna system, the following precautions should be observed:

- Since the three RF signal ports of most SPDTs are electric, ensure that they are not short-circuited to the ground by using DC block capacitors.
- Pay attention to the logic control instructions in the SPDT specification. Note which RF patch is connected inside the SPDT when the control pin is at a high or low level. In addition, verify the specific high and low level voltage ranges of the control pin.
- Design a short-circuit detection and protection circuit for the active antenna to prevent damage to GNSS modules and devices.
- When connecting the antenna detection circuit to the RF path, add an inductor with an inductance of at least 68 nH at the connection point to avoid increasing the RF loss. The inductor pad that is close to the antenna should be placed on the RF trace line.
- Some modules may already have integrated antenna detection and protection circuits, eliminating the need for additional detection and protection circuits. Design the dual antenna system according to the specific requirements of the modules in use.

5 Interference

Since GNSS signals are usually very weak, the sensitivity of GNSS receivers to interference from the surrounding environment is heightened.

5.1. Interference Sources

In the real-world operating environment of a GNSS module, the primary two interference sources are:

- DC-DC converters and other power supply network components, clock crystals, camera circuits, and other common devices and circuits known to cause interference.
- RF signals emitted by other wireless communication systems, e.g., cellular communication systems, Wi-Fi, and Bluetooth.

5.2. Common Interference Components and Circuits

Certain electronic components and circuits can produce interference signals at various frequencies during their operation, potentially affecting the performance of the GNSS module. It is crucial to thoroughly assess these aspects in the early stages of product design to proactively mitigate interference.

Key consideration during the design process include:

- Make sure DC-DC converters, microcontrollers, crystals, LCM, cameras, and other high-speed components and interfaces are positioned on the motherboard opposite to the module. Keep them away from the module and antenna as far as possible, preferably by placing them diagonally relative to the module and antenna.
- Minimize the length of interference signal (e.g., from USB, LCM, camera, crystal, etc.) trace lines and place them on the inner layers shielded by the ground plane. On the same layer or adjacent layers, avoid running these lines in close parallel and use ground vias for shielding. Keep the lines and their vias away from the modules and antennas.

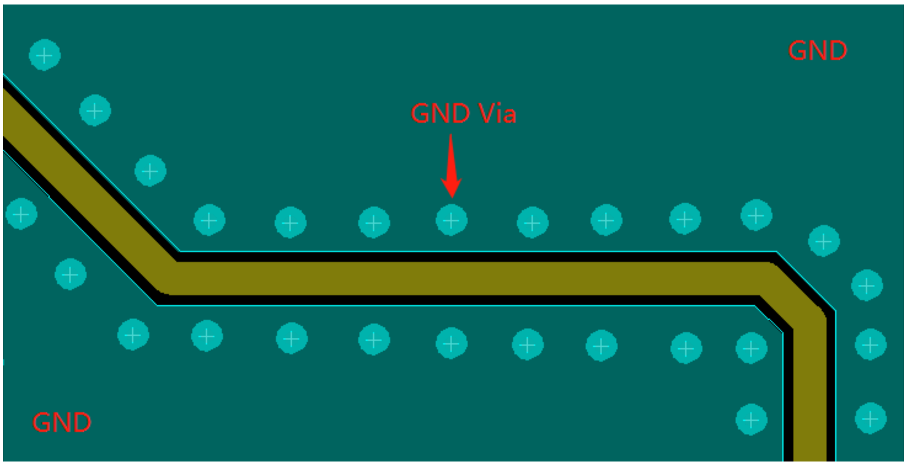
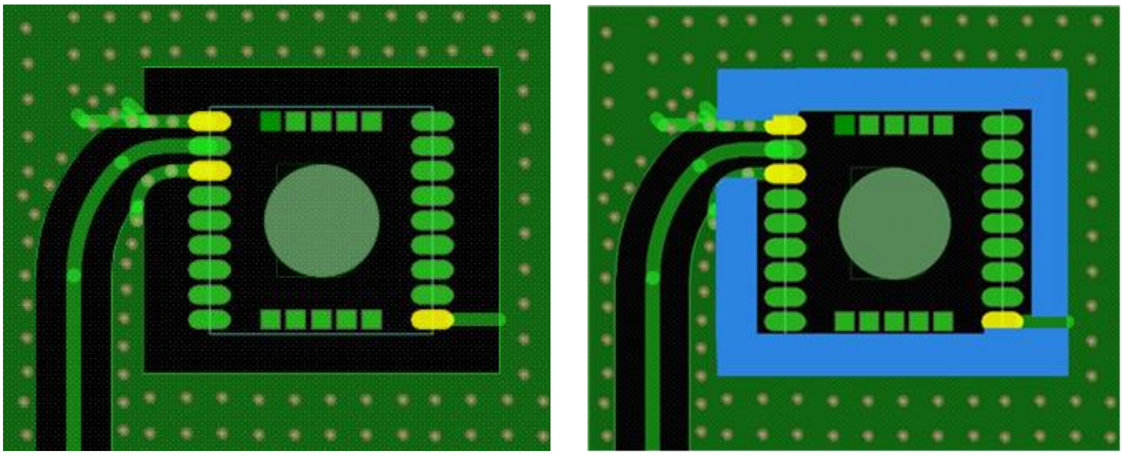


Figure 21: Shielding of Interference Signal Trace Lines

- It is recommended to reserve series and parallel positions at the input and output ports of the DC-DC converters to facilitate the use of magnetic beads and decoupling capacitors to optimize interference.
- If the camera circuit and similar components are connected to the main board with cables, it is recommended to use cables with shielding functions to prevent the interference signal of the camera circuit from radiating outward through the cables.
- Ensure that the GND pins of the module are in full contact with the GND of the PCB, and keep the ground wires as short as possible.

The three yellow pins in the figure below are GND pins of the module. It is recommended to add GND and GND vias in the blue part according to the right figure instead of the left figure.



GND Not Recommended **GND Recommended**

Figure 22: GND Design

- When using decoupling capacitors, ensure that the ground point is in full contact with the main ground and pay attention to the operating temperature range of the capacitors. Due to the differences in the dielectric materials used, some capacitor series cannot support -40 °C, such as HG, SL, Z5U, Y5V, and others in the figure below cannot be used in environments with -40°C.

Dielectric	Reference Temperature Point	Temperature Coefficient	Operation Temperature Range
COG	20°C	0±30 ppm/℃	-55℃～125℃
COH	20°C	0±60 ppm/℃	-55℃～125℃
HG	20°C	-33±30 ppm/℃	-25℃～85℃
LG	20°C	-75±30 ppm/℃	-25℃～85℃
PH	20°C	-150± 60 ppm/℃	-25℃～85℃
RH	20°C	-220± 60 ppm/℃	-25℃～85℃
SH	20°C	-330± 60 ppm/℃	-25℃～85℃
TH	20°C	-470± 60 ppm/℃	-25℃～85℃
UJ	20°C	-750± 120 ppm/℃	-25℃～85℃
SL	20°C	-1000～+140 ppm/℃	-25℃～85℃
X7R	20°C	±15%	-55℃～125℃
X5R	20°C	±15%	-55℃～85℃
X7S	20°C	±22%	-55℃～125℃
X6S	20°C	±22%	-55℃～105℃
Z5U	20°C	-56%～+22%	10℃～85℃
Y5V	20°C	-80%～+30%	-25℃～85℃

Figure 23: Capacitors and Operating Temperature

- Using a shielding cover is a good measure to contain interference signals within a specific area. Please note that holes and slots on the shielding cover can affect its shielding effectiveness, and may even turn it into an antenna for radiating interference signals. The shielding cover should be airtight and fully connected to the ground.
- Place common interference components and circuits inside the shielding cover, such as DC-DC converters, microcontrollers, and crystals.
- Opt for a shielding cover made of Copper-nickel-zinc Alloy, with a thickness not less than 0.2 mm.

5.3. Co-existence with Wireless Communication Systems

Since GNSS signals are usually very weak, a GNSS receiver could be vulnerable to environmental interference. According to 3GPP specifications, a cellular terminal should transmit a signal of up to 33 dBm at GSM bands, or of about 24 dBm at WCDMA and LTE bands, or of about 26 dBm at 5G bands. Consequently, coexistence with other wireless communication systems must be optimized to avoid significant deterioration of GNSS performance.

In a complex communication environment, interference may be caused by in-band and out-of-band signals as described in this chapter. Suggestions are also provided for decreasing the impact of interference signals that will ensure the interference immunity of a GNSS receiver.

5.3.1. In-band Interference

In-band interference refers to the signal whose frequency is within or near the operating frequency range of a GNSS signal. For example, GPS L1 is centered at 1575.42 MHz with a bandwidth of 2.046 MHz. As shown in the figure below, the frequency of the interfering signal is within the GPS operation band, and the power of the interfering signal is higher than the power value of the received GPS signal.

See the following figure for more details.

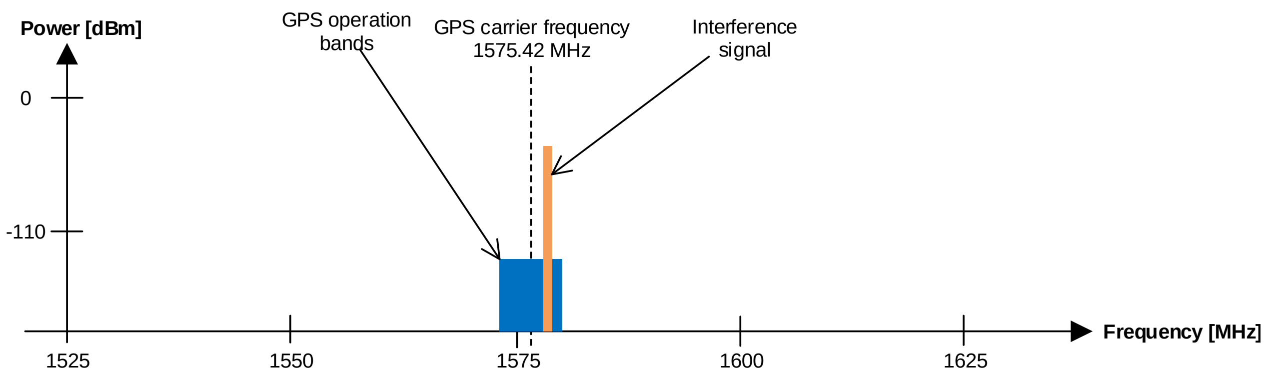


Figure 24: In-band Interference on GPS L1

The most common in-band interferences usually come from:

- Harmonics, crystals, high-speed signal lines, MCUs, switch-mode power supply etc., or
- Intermodulation from different communication systems.

The table below lists some common frequency combinations and potential in-band interferences generated by two kinds of out-of-band signal intermodulation or the second harmonic of LTE Band 13.

Table 3: Intermodulation Distortion (IMD) Products

Source F1	Source F2	IM Calculation	IMD Products
GSM850/Band 5	Wi-Fi 2.4 GHz	F2 (2412 MHz) - F1 (837 MHz)	IMD2 = 1575 MHz
Band 1	n78	F2 (3500 MHz) - F1 (1925 MHz)	IMD2 = 1575 MHz
DCS1800/Band 3	PCS1900/Band 2	2 × F1 (1712.6 MHz) - F2 (1850.2 MHz)	IMD3 = 1575 MHz
PCS1900/Band 2	Wi-Fi 5 GHz	F2 (5280 MHz) - 2 × F1 (1852 MHz)	IMD3 = 1576 MHz
LTE Band 13	-	2 × F1 (786.9 MHz)	IMD2 = 1573.8 MHz

5.3.2. Out-of-band Interference

Strong signals transmitted by other communication systems can cause a GNSS receiver saturation, thus greatly deteriorating its performance, as illustrated in the following figure. In practical applications, common strong interference signals originate from wireless communication modules, such as GSM, 3G, LTE, 5G, Wi-Fi and Bluetooth.

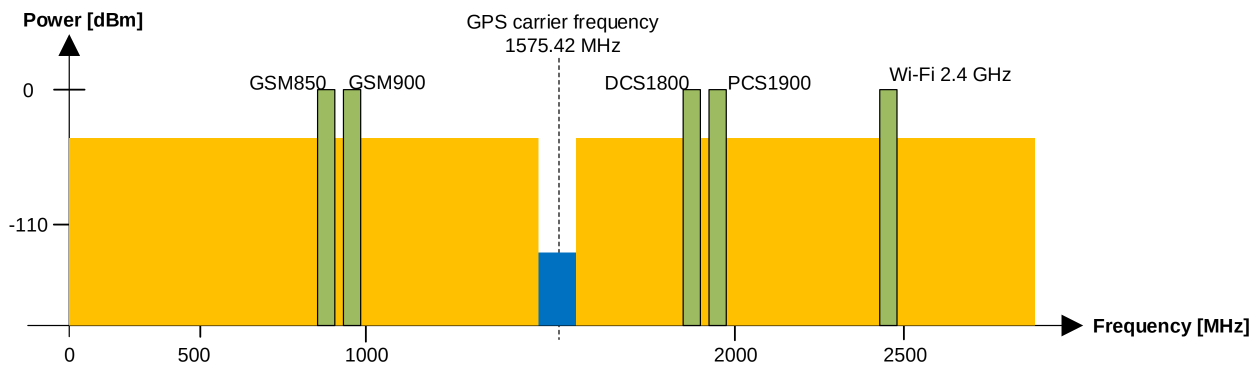


Figure 25: Out-of-band Interference on GPS L1

5.3.3. Ensuring Interference Immunity

There are several recommended strategies to decrease the impact of interference signals and thus ensure the interference immunity of a GNSS receiver:

- Keep the GNSS antenna away from interference sources.
- Add a band-pass filter in front of the GNSS module.
- Use shielding, multi-layer PCB, and ensure adequate grounding.
- Optimize layout and component placement of the PCB and the whole device.

The following figure illustrates the interference source and the potential interference path. A complex communication system usually contains RF power amplifiers, MCUs, crystals, etc. These devices should be far away from a GNSS receiver, or a GNSS module. In particular, shielding should be used to prevent strong signal interference for power amplifiers. The cellular antenna should be placed away from a GNSS receiving antenna to ensure enough isolation. Usually, a good design should provide at least a 20 dB isolation between two antennas. Take DCS1800, for example, the maximum transmitted power of DCS1800 is around 30 dBm. After a 20 dB attenuation, the signal received by the GNSS antenna will be around 10 dBm, which is still too high for a GNSS module. With a GNSS band-pass filter with around 40 dB rejection in front of the GNSS module, the out-of-band signal will be attenuated to -30 dBm.

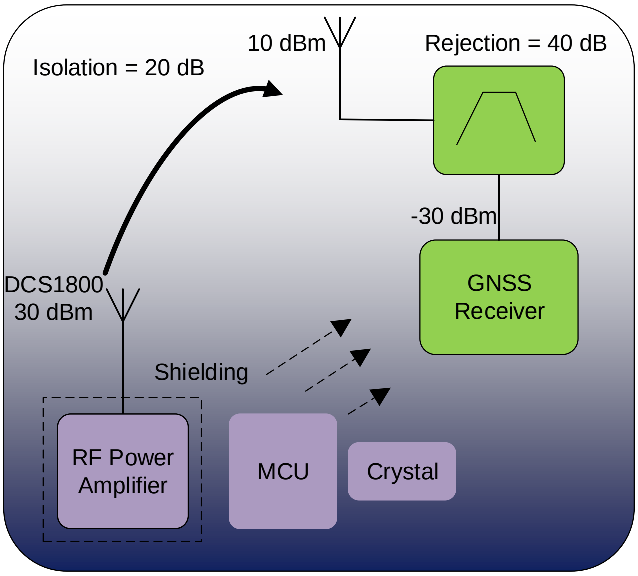


Figure 26: Interference Source and Its Path

6 Antenna Placement and Fixing

6.1. Antenna Placement

The placement of the GNSS antenna is crucial for optimal receiving performance and positioning accuracy. By considering the surrounding environment and making appropriate adjustments, we can increase the number of visible satellites and improve the antenna's performance. For example, when using a ceramic patch antenna, it is recommended to position it horizontally with the radiation surface facing the open sky, while avoiding obstacles and interference.

If the GNSS antenna is placed on the roof of a building, as illustrated in the figure below, position 1 is the ideal position. If this position is not feasible, position 2 can be considered as an alternative, although it may impact satellite visibility and signal strength, thus affecting the receiver performance. Position 3 is not recommended.

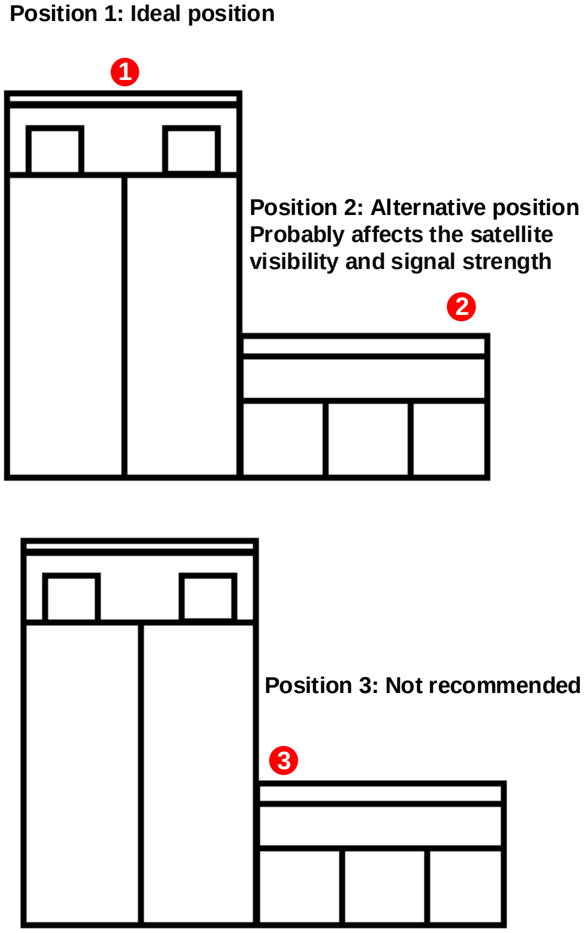


Figure 27: Antenna Positions on the Roof of a Building

In automotive applications, positions 1 and 2 in the figure below are ideal positions for GNSS antenna. If these positions are not feasible, positions 3 and 4 under the roof and glass are alternative options. However, the visible satellites and signal intensity will be affected in these positions. It is advisable not to use protective films with metal material on the glass, as they can interfere with the GNSS signal reception.

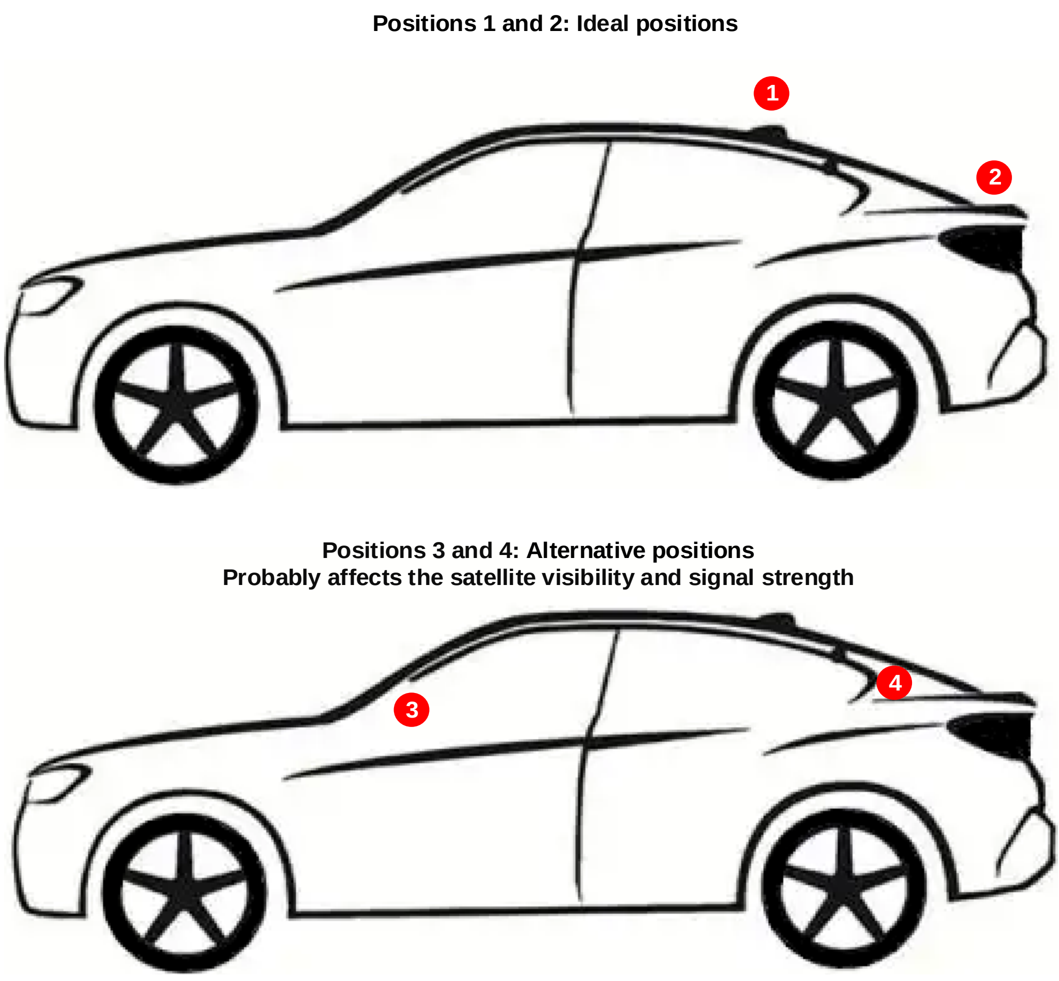


Figure 28: Antenna Positions for Automotive Application

In the application scenarios of two-wheeled scooters and two-wheeled electric vehicles, position 1 in the figure below is the ideal position. If this position is not feasible, positions 2 and 3 can also be considered, although they may have some impact on satellite visibility and signal strength

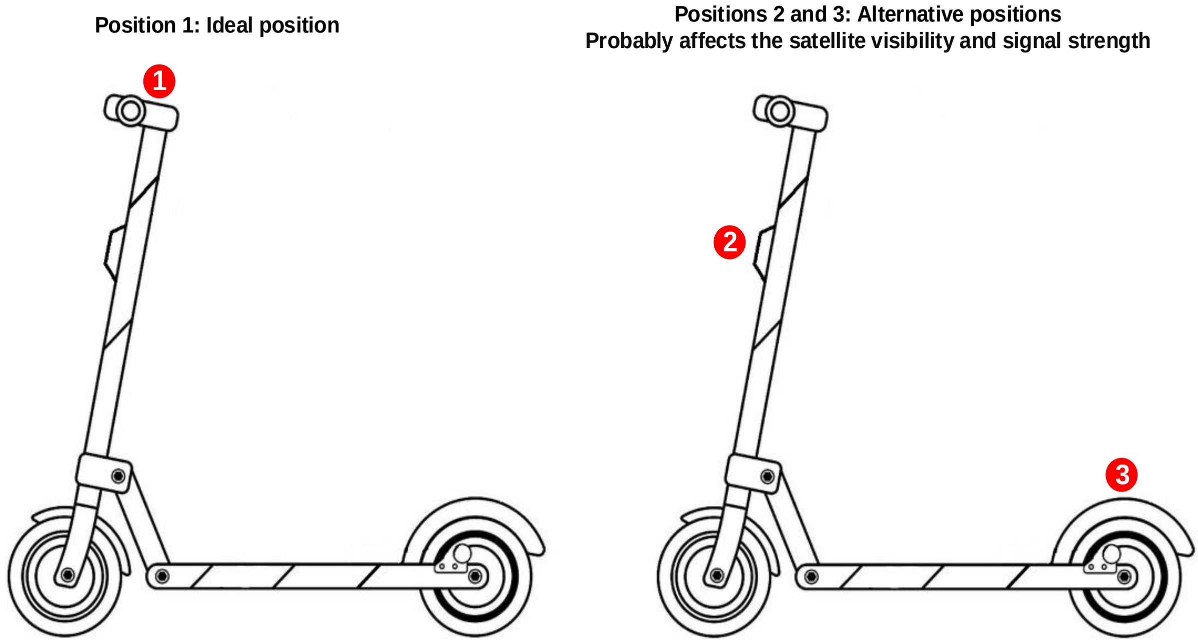


Figure 29: Antenna Positions for Two-wheeled Vehicle

6.2. Antenna Fixing

To improve reliability and prevent antennas from falling off due to intense vibrations in some application scenarios, apply silicone around ceramic antennas. The recommended silicone model is K704 from Kafuter.

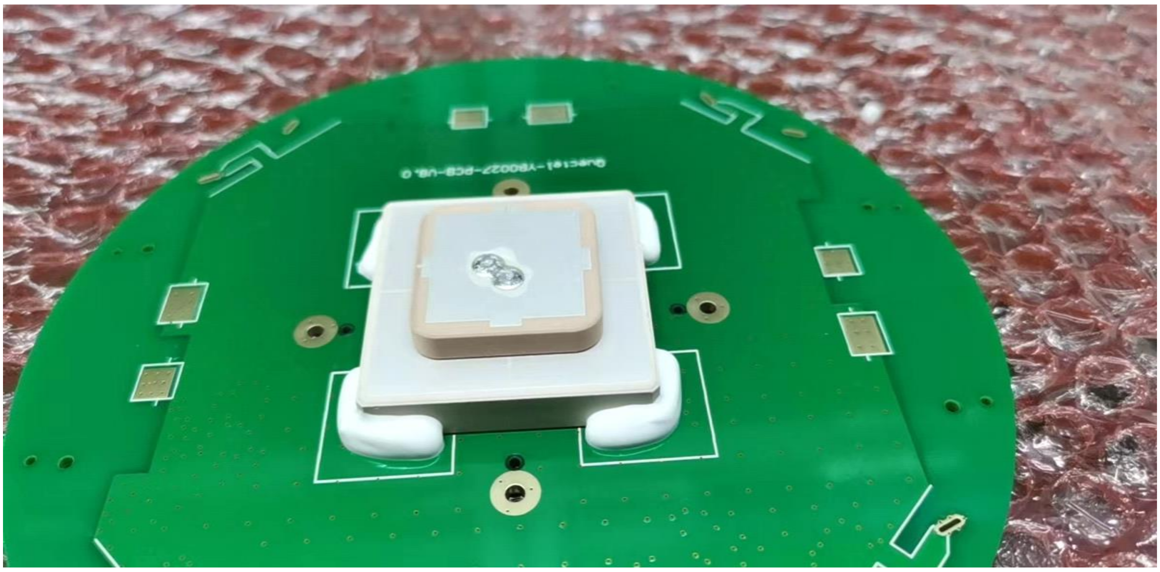


Figure 30: Recommended Silicone for Antenna Fixing

7 Recommended Quectel Antenna Models

It should be noted that different modules have various requirements, therefore it is crucial to follow the specific requirements outlined in the hardware design document. Quectel offers a range of GNSS antennas in various types and sizes, along with customized services tailored to your requirements. If you have any questions, contact Quectel Technical Support (support@quectel.com).

You can choose the appropriate antenna from the following models according to your requirements.

7.1. Embedded Ceramic Antenna

Figure 31: Embedded Ceramic Antenna

Table 4: Embedded Ceramic Antenna

Antenna Model	Constellation and Band
YFGC010WWA	GPS: L1 Galileo: E1 BDS: B1C QZSS: L1
YFGC015WWA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1
YFGC018WWA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1
YFGC025WWC	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1
YFGC035WWA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1
YFGC225WWA	GPS: L1, L5 Galileo: E1, E5a BDS: B1C, B2a QZSS: L1, L5 NavIC: L5
YFGC233WWA	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5
YFGC235WWA	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5
YFGC238WWA	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5
YFGC245WWB	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5

7.2. Passive Ceramic Antenna with Cable

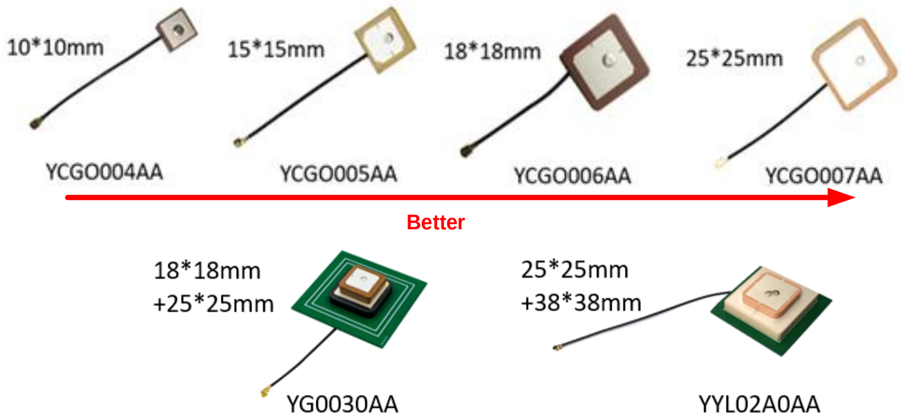


Figure 32: Passive Ceramic Antenna with Cable

Table 5: Passive Ceramic Antenna with Cable

Antenna Model	Constellation and Band
YCGO004AA	GPS: L1 Galileo: E1 BDS: B1C QZSS: L1
YCGO005AA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C QZSS: L1
YCGO006AA	GPS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1
YCGO007AA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1
YG0030AA	GPS: L1, L5 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5
YYL02A0AA	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5

7.3. Active Ceramic Antenna with Cable

Figure 33: Active Ceramic Antenna with Cable

Table 6: Active Ceramic Antenna with Cable

Antenna Model	Constellation and Band	Internal Framework	LNA Gain
YFGA010E3AM	GPS: L1 Galileo: E1 BDS: B1C QZSS: L1	SAW + LNA	17 ±3 dB
YFGA015E3AM	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C QZSS: L1	SAW + LNA	17 ±3 dB
YFGA018E3AM	GPS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1	SAW + LNA	17 ±3 dB
YFGA025E3CM	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1	SAW + LNA	17 ±3 dB

Antenna Model	Constellation and Band	Internal Framework	LNA Gain
YFGA225E3AM	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	SAW + LNA	17 ±3 dB
YFGA235E3AM	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	SAW + LNA	17 ±3 dB
YFGC007E3A	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	SAW + LNA	17 ±3 dB
YFGA245E3AM	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	SAW + LNA	17 ±3 dB

7.4. External Active Antenna

- YEGB000Q1C
- 45 × 36 × 15.8 mm

- YEGN001Q1A
- 53 × 48 × 20 mm

- YEGD006U1A
- 90 × 85 × 25.8 mm

Figure 34: External Active Antenna

Table 7: External Active Antenna

Antenna Model	Constellation and Band	Internal Framework	LNA Gain
YEGB000Q1C	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C	SAW + LNA	21 ±3 dB

Antenna Model	Constellation and Band	Internal Framework	LNA Gain
	QZSS: L1		
YEGN001Q1A	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	SAW + LNA	21 ±3 dB
YEGD006U1A	GPS: L1, L2C, L5 GLONASS: L1, L2, L3 Galileo: E1, E5a, E5b, E6 BDS: B1C, B1I, B2a, B2b, B2I, B3I QZSS: L1, L2C, L5, L6 NavIC: L5 L band	SAW + LNA	30 ±3 dB

7.5. Other Antennas

- YEGT000W8A

- YEGM013AA

- YEGN007AA
- YEGN007BA
- YEGN009AA
- YEGN009BA

Figure 35: Other Antennas

Table 8: Other Antennas

Antenna Model	Constellation and Band	Internal Framework	LNA Gain
YEGT000W8A	GPS: L1, L5 GLONASS: L1 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	SAW + LNA	28 ±2 dB
YEGM013AA	GPS: L1, L2C, L5 GLONASS: L1, L2, L3 Galileo: E1, E5a, E5b, E6	SAW + LNA	40 ±2 dB

Antenna Model	Constellation and Band	Internal Framework	LNA Gain
	BDS: B1C, B1I, B2a, B2b, B2I, B3I QZSS: L1, L2C, L5, L6 NavIC: L5		
YEGN007AA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1	SAW + LNA	17 ±3 dB
YEGN007BA	GPS: L1 GLONASS: L1 Galileo: E1 BDS: B1C, B1I QZSS: L1	SAW + LNA	28 ±3 dB
YEGN009AA	GPS: L1, L5 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	Dielectric Filter + LNA	17 ±3 dB
YEGN009BA	GPS: L1, L5 Galileo: E1, E5a BDS: B1C, B1I, B2a QZSS: L1, L5 NavIC: L5	Dielectric Filter + LNA	28 ±3 dB

NOTE

For details on recommended Quectel antennas, see the corresponding antenna datasheet or contact Quectel Technical Support (support@quectel.com).

8 Appendix References

Table 9: Terms and Abbreviations

Abbreviation	Description
3GPP	3rd Generation Partnership Project
BDS	BeiDou Navigation Satellite System
C/N_0	Carrier-to-noise Ratio
DC	Direct Current
DC-DC	Direct Current to Direct Current
DCS1800	Digital Cellular System at 1800 MHz
ESD	Electrostatic Discharge
Galileo	Galileo Satellite Navigation System (EU)
GLONASS	Global Navigation Satellite System (Russia)
GND	Ground
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HPBW	Half-power Beamwidth
IM	Inter-Modulation
IMD	Intermodulation Distortion
LCM	“LCD Module”/Liquid Crystal Monitor
LNA	Low-noise Amplifier
LTE	Long-term Evolution

Abbreviation	Description
NF	Noise Figure
PCB	Printed Circuit Board
PCO	Phase Center Offset
PCV	Phase Center Variation
PIFA	Planar Inverted F-shaped Antenna
QZSS	Quasi-zenith Satellite System
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
RTK	Real-Time Kinematic
SAW	Surface Acoustic Wave
SMD	Surface Mount Device
SPDT	Single-Pole Double-Throw
USB	Universal Serial Bus
VSWR	Voltage Standing Wave Ratio
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity