Antenna Design Guide

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About the Document

Revision History

Version	Date	Author	Description
1.0	2012-06-09	David WEI	Initial
1.1	2012-06-15	David WEI	Modified Figure 1
1.2	2012-08-01	David WEI	Added contact information for antenna manufacturers: Antenova and Pulse Electronics
1.3	2012-11-21	David WEI	Added contact information for GLONASS antenna manufacturer INPAQ
1.4	2013-07-10	David WEI	1. Added ceramic chip antennas 2. Updated contact information
1.5	2014-11-21	Jackie WANG	Added the antenna performance and LDS antenna
1.6	2015-04-11	Jackie WANG	Added applicable modules
1.7	2016-01-06	Mark ZHANG	1. Added external PCB antennas 2. Added contact information for antenna manufacturer SAINTENNA and JINGHONG
1.8	2016-06-01	Mark ZHANG	1. Updated the contact information of antenna manufacturer JESONCOM 2. Updated the address and contact information of antenna manufacturer Antenova
1.9	2017-07-14	Vick YANG	1. Added description of metal frame antennas in Chapter 3.8 2. Added description of internal Wi-Fi laminated antennas in Chapter 7 3. Updated antenna suppliers information in Chapter 8: ● Updated contact information of antenna manufacturers SAINTENNA and INPAQ ● Deleted information of antenna manufacturer JINGHONG ● Added information of antenna manufacturer

			SHEN XUN
2.0	2018-01-02	Vick YANG/ Beny ZHU	1. Optimized the description of EIRP (Effective Isotropic Radiated Power) in Chapter 2.1. 2. Updated the design note (item 3) for internal Wi-Fi laminated antenna. 3. Added Chapter 8: GNSS Antenna Isolation Design Requirements. 4. Updated the address and contact information (tel. number, email address and fax number) of antenna supplier Pulse. 5. Added Sunnyway and VLG as new antenna suppliers.
3.0	2019-06-21	Riley XU	Numerous changes have been made to this document and thus it is recommended to read in its entirety.
3.1	2019-07-04	Riley XU	Updated antenna suppliers' information
3.2	2020-02-13	Riley XU	1. Deleted antenna suppliers' information. 2. Added Quectel antenna design service information in Chapter 9.
3.3	2021-06-24	Riley XU/ Kevin TU	1. Updated the document name to Quectel_Antenna_ Design_Guide. 2. Updated the classification of antennas for this document. 3. Updated the example figures (Chapters 3–7). 4. Modified part of the descriptions of design guidelines (Chapter 3–7 and Chapter 8.3).

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1 Recommended Component Placement on Main PCB

This document is applicable to all Quectel modules.

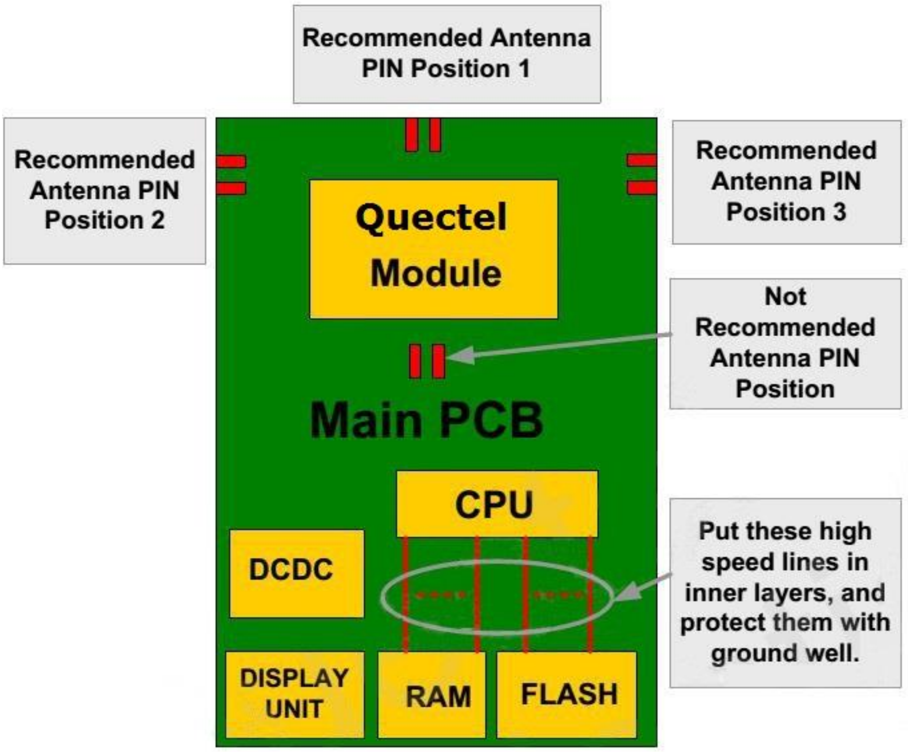


Figure 1: Recommended Component Placement

Notes:
1. It is suggested to keep the RF ports at the edge of the main PCB, and keep them away from the other circuits. Avoid vias and routing the RF trace to a different layer. RF traces should be designed to have an impedance of 50 Ω. Please keep the distance between RF ports and antennas as short as possible. If there is a long distance and it cannot be shortened anymore, it is recommended to use antenna cables for the antenna connection.
2. Please put antenna feed points at the edge of the main PCB, rather than in the center. For two antennas working at a similar frequency range, the distance between them should be more than the quarter-wavelength at the lowest frequency. When the antennas are too close, they are recommended to be orthogonal to each other.

3.	Generally speaking, the isolation between the antennas should be at least 10 dB to avoid interference.
4.	Please keep the antenna as far away as possible from CPU, SDRAM, flash, DC-DC converters, and FPC connectors of displays. The antenna should be placed on opposite side of PCB on which these components are mounted.
5.	Please keep the high-speed traces between CPU and SDRAM/flash/FPC connectors of displays as short as possible, and put these traces in inner layers with ground shielding on not only upper and lower layers but also right and left sides. Use EMI filters on high-speed traces between CPU and display FPC if necessary.
6.	Please put CPU, SDRAM, flash, DC-DC converters, and FPC connectors of displays into the shielding case, and a copper-nickel-zinc alloy shielding case is preferred.

2 Basic Parameters and Requirements of Antennas

2.1. Basic Parameters of Antennas

- **Gain (dBi):**
  The ratio of “power of antenna” and “power of isotropic radiation from an ideal current source” in maximum transmitting direction with the same input power. “dBi” is widely used as the unit of antenna gain.

- **Gain (dBd):**
  The ratio of “power of antenna” and “power of half wave dipole antenna” in maximum transmitting direction with the same input power. When it represents the same gain, one formula indicating relationship between dBi and dBd is given as below: dBi = dBd + 2.15.

- **Directivity:**
  The ratio of “power of antenna” and “power of isotropic radiation from an ideal current source” in maximum transmitting direction with the same radiated power.

- **Efficiency:**
  The ratio of the antenna radiation power and antenna input power.

Gain = Directivity × Efficiency
Efficiency = Output Power / Input Power

- **APIP (Antenna Port Input Power):**
  The input power of antenna.

- **EIRP (Effective Isotropic Radiated Power):**
  EIRP (Effective Isotropic Radiated Power) is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain. It is also called Equivalent Isotropic Radiated Power. EIRP can take into account the losses in transmission line and connectors and include the gain of the antenna. The EIRP is often stated in terms of decibels over a reference power emitted by an isotropic radiator with an equivalent signal strength. The EIRP allows comparisons between

different emitters regardless of type, size or form. From the EIRP, and with knowledge of a real antenna's gain, it is possible to calculate real power and field strength values.

EIRP = Pt × Gt
- Pt: the output power of the transmitter (unit: dBm)
- Gt: the antenna gain of the transmitting antenna (unit: dBi)

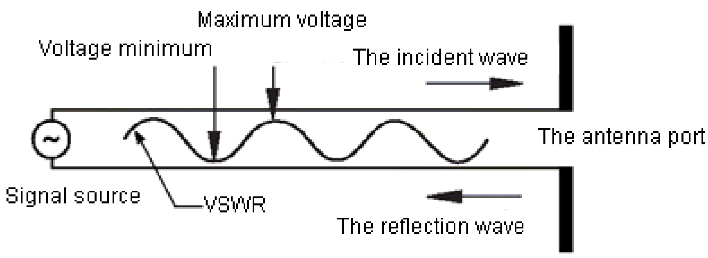
Logarithmic (dB) formula: EIRP = P - Loss + G
- P: output power of transmitter (unit: dBm)
- Loss: feeder loss between transmitter output terminal and antenna feed source (unit: dB)
- G: antenna transmission gain (unit: dBi)

- **PEIRP (Peak Effective Isotropic Radiated Power):**
  The peak value of EIRP.

- **ERP (Effective Radiated Power):**
  Comparing to half wave dipole antenna, it is the power obtained in maximum transmitting direction.

- **VSWR (Voltage Standing Wave Ratio):**

$$VSWR = \frac{Vmax}{Vmin} = \frac{1+|\Gamma|}{1-|\Gamma|}$$



VSWR is commonly represented in Return Loss (RL) (indicated as S11) in engineering:

$$RL = -20\lg\frac{V+1}{V-1}\ (dB)$$

The corresponding relationship between RL and VSWR is shown in the table below:

Table 1: VSWR and Return Loss

VSWR	1.20	1.25	1.30	1.35	1.40	1.50	2.00
Return Loss (dB)	-20.83	-19.09	-17.69	-16.54	-15.56	-13.98	-9.54

2.2. Basic Requirements of Antennas

Table 2: Basic Requirements of Antennas

Items	Requirements
Frequency Band	Determined by the supported operating bands of devices
VSWR	≤ 3
Efficiency	Converted based on OTA metrics
Gain (dBi)	No mandatory requirement. If you need to pass a specific operator's certification, the operator's requirements can be referred to.
Max Input Power (W)	50
Input Impedance (Ω)	50
Polarization Type	● Linear Polarization: Horizontal Linear Polarization Vertical Linear Polarization ● Circular Polarization: Right-Hand Circular Polarization (RHCP) Left-Hand Circular Polarization (LHCP)

3 Embedded 2G/3G/4G/5G Antennas

3.1. Flexible Printed Circuit (FPC) Antenna

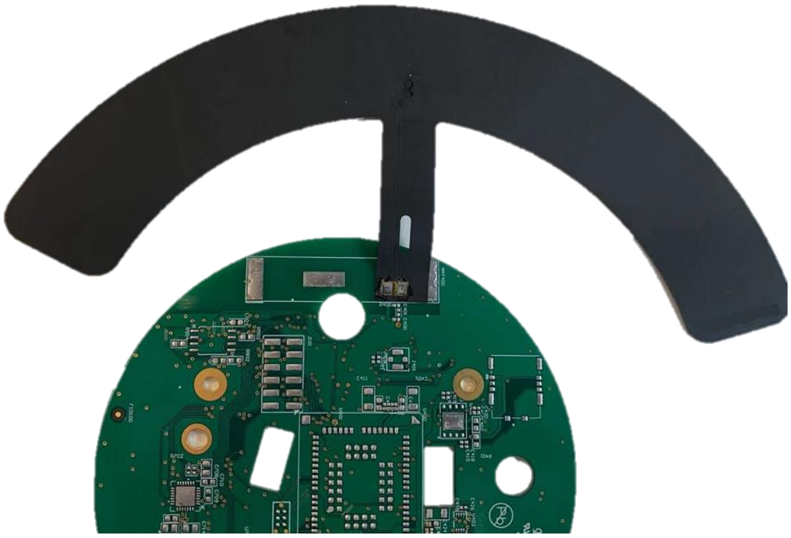


Figure 2: FPC Antenna (PIFA Antenna, Fed from Soldering Pads)

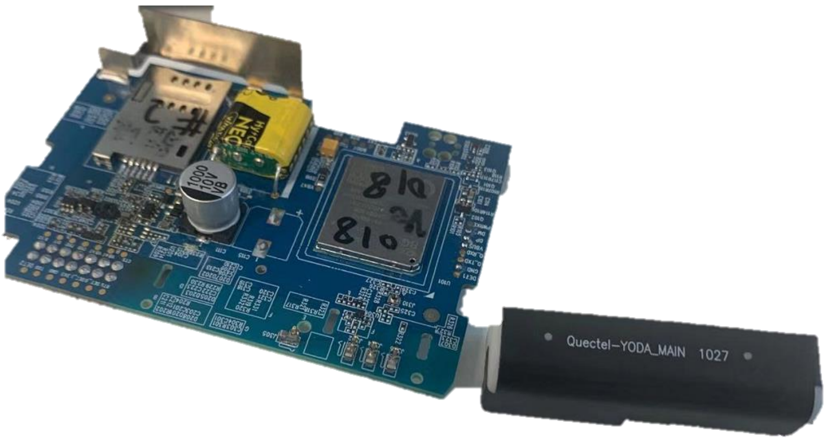


Figure 3: FPC Antenna (Fed from Flat Spring)

Figure 4: FPC Antenna (PIFA Antenna, Fed from Thimble)

Notes:
1. The FPC antenna can be fixed on the inside of a plastic device housing. To increase the solidity, heat staking can be applied to fix the antenna. This type of antenna does not occupy the motherboard area, so it is preferred for space-demanding applications such as PDA and automotive devices. According to division of frequency bands, three feed points are usually reserved for this type of antenna: an intermediate signal point, and two ground points on two sides. Usually, the signal point with one ground feed point is used for the antenna debug; and when the bandwidth of a high-frequency band is not enough during antenna tuning, the other ground feed point will be used as a parasite to increase the high-frequency bandwidth.
2. Keep the distance between antenna and the main PCB more than 5 mm (for a particular distance, refer to the evaluation result of the antenna supplier).
3. For the device housing with a curved surface on the inside, relief hole and relief groove should be applied when fixing the antenna to avoid warpage and unstable fixation. As effectiveness of the adhesive (usually 3M adhesive is used) will be weakened under high ambient temperature, heat staking or other mounting methods should be used to fix the FPC antenna.
4. There are usually three contacting forms between the motherboard and antennas: soldering pads, probes or flat spring. You can select according to actual applications.

3.2. Flat Spring Antenna

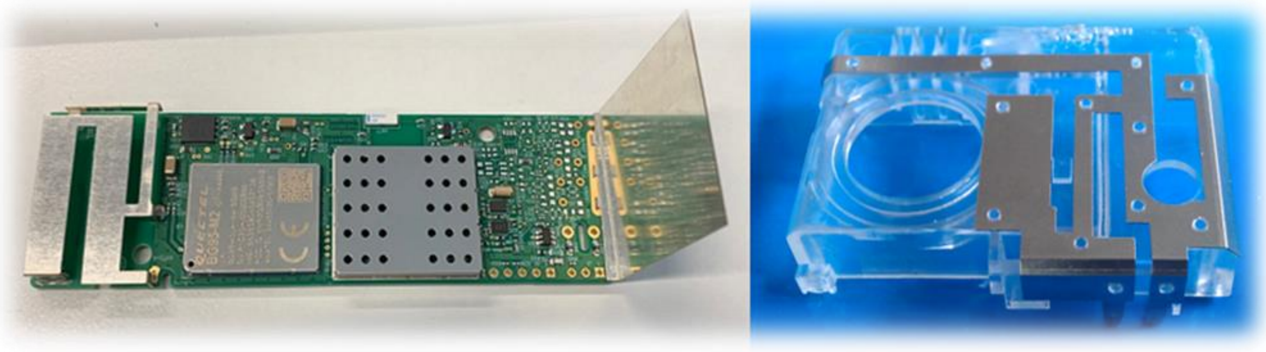


Figure 5: Example of a Flat Spring Antenna

Notes:

1. This type of antenna generally requires three feed points: an intermediate signal feed point, and two ground feed points on two sides. Usually, the signal point with one ground feed point is used the antenna debug, and when the bandwidth of a high-frequency band is not enough during antenna tuning, the other ground feed point will be used as a parasite to increase the high-frequency bandwidth. (RF engineers and structural engineers should both be involved during antenna selection and initial design stages. And the bracket should be designed as required by the antenna supplier).
2. Because, for this type of antenna, the material is hard, the routing is relatively inflexible, and trace area is generally larger, the requirements for ambient conditions are strict.

3.3. Laser Direct Structuring (LDS) Antenna

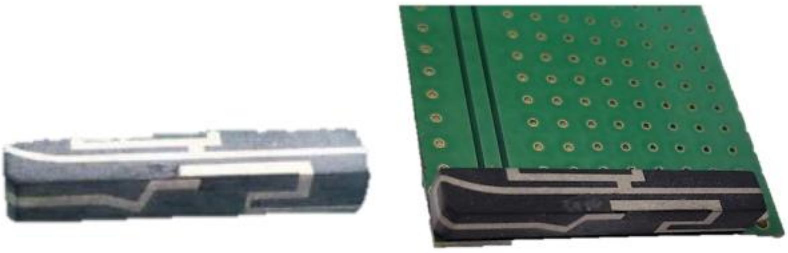


Figure 6: Example of an LDS Antenna

Notes:

1. The antenna is designed and structured directly on the bracket (carrier) or device housing by laser and plating. The antenna features high compatibility and precision, stable performance as well as simple and environment-friendly manufacturing process.

2.	Trace can be routed onto the device housing or bracket, thus saving space within the device.
3.	The LDS production process and the material of bracket make the price of LDS antenna much more expensive than other antennas.
4.	As the antenna is attached to a plastic bracket, any deformation of the bracket may cause a fracture of the antenna.

3.4. SMD Antenna

Figure 7: Example of a SMD Antenna

Notes:	
1.	This type of antenna requires large clearance and costs more.
2.	The requirements for reserved space and antenna placement proposed in antenna supplier's datasheet should be strictly followed.
3.	The antenna can be surface mounted and it should be placed at the edge of the PCB.
4.	The matching between ambient conditions and the antenna has a notable influence on antenna performance.

3.5. PCB Trace Antenna

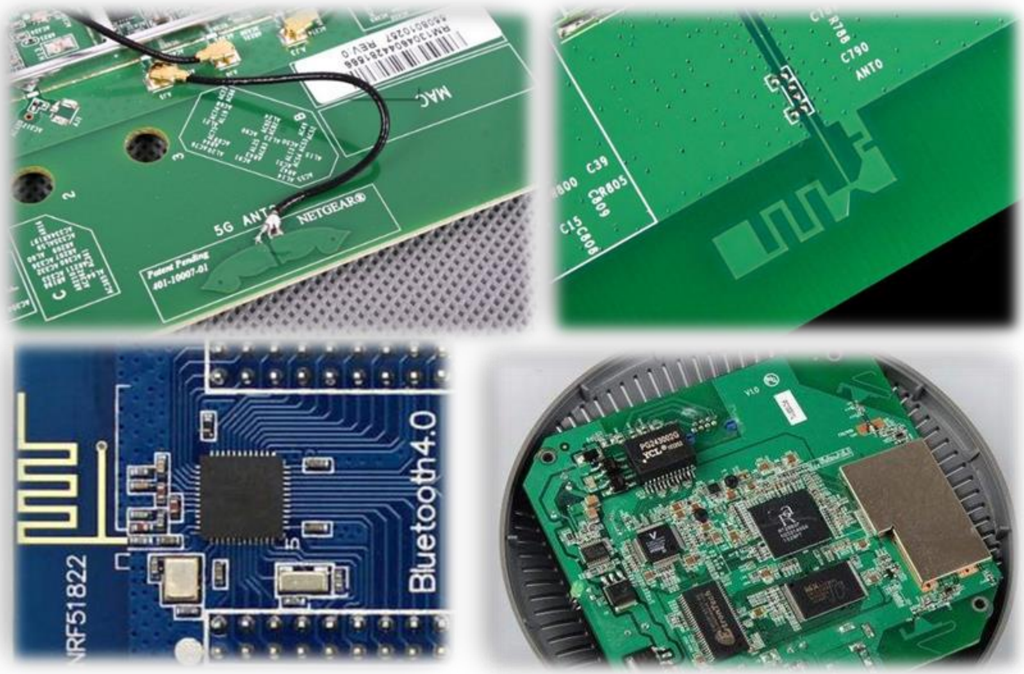


Figure 8: Example of PCB Trace Antennas

Notes:
1. Antenna design assessment should be carried out at the initial stage of PCB layout to reserve an appropriate area for the antenna.
2. The ambient conditions will notably influence the antenna performance. And the material, placement and layout will all affect the antenna performance.
3. The antenna is mainly used for devices with limited operation bands. Besides the antenna trace area, the length of the ground plane of PCB should not be less than the quarter-wavelength at the lowest frequency.

3.6. Other Antennas

Figure 9: Example of Other Antennas

Notes:	
1.	These antennas listed above are typically fixed on the inside of a plastic device housing or mounted in a suitable socket, and thus they do not occupy any space on the main PCB.
2.	The antenna takes large space and cannot be surrounded by any metal component in close proximity. The length of the antenna usually ranges from one quarter wavelength to one half wavelength.
3.	The antenna is usually connected to the RF output port of the main PCB via a RF connector or soldering pad.
4.	For part of antennas, it is necessary to make use of the device's or PCB's GND during antenna tuning,

4 External 2G/3G/4G/5G Antennas

4.1. Dipole Antenna

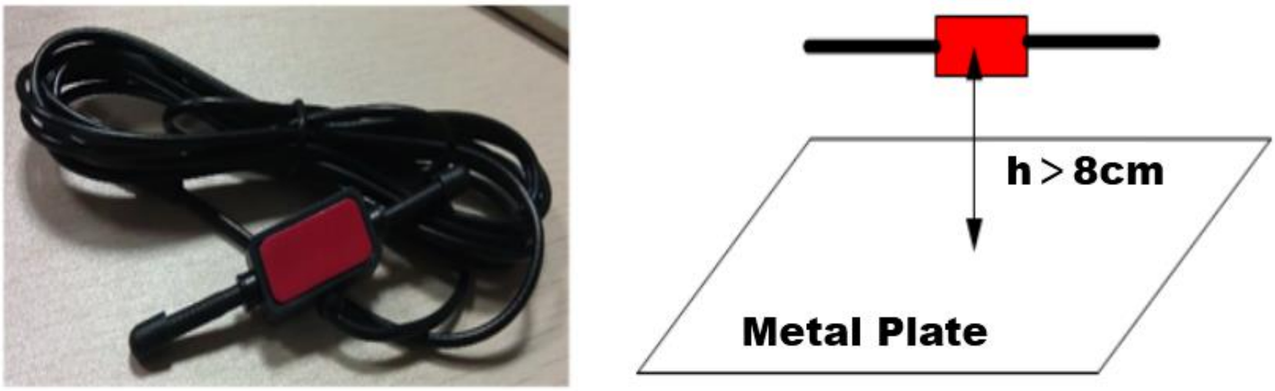


Figure 10: Example of a Dipole Antenna

Notes:
1. The height from the reflective metal plate and the antenna should be at least 8 cm, and the frequency band is limited.
2. As the antenna cable length will impact the antenna performance, low-loss cables are recommended.

4.2. Sucker Antenna

Figure 11: Examples of Sucker Antennas

Notes:
1. Sucker antennas are easy to move and install, but support limited frequency bands. Models of this type of antenna shall be selected depending on particular operating environments.
2. Place the antennas on metal surfaces to achieve the best performance.
3. As the length of an antenna cable negatively affects the antenna performance, it is recommended to use low-loss cables when long trace is required.

4.3. Combined Antenna

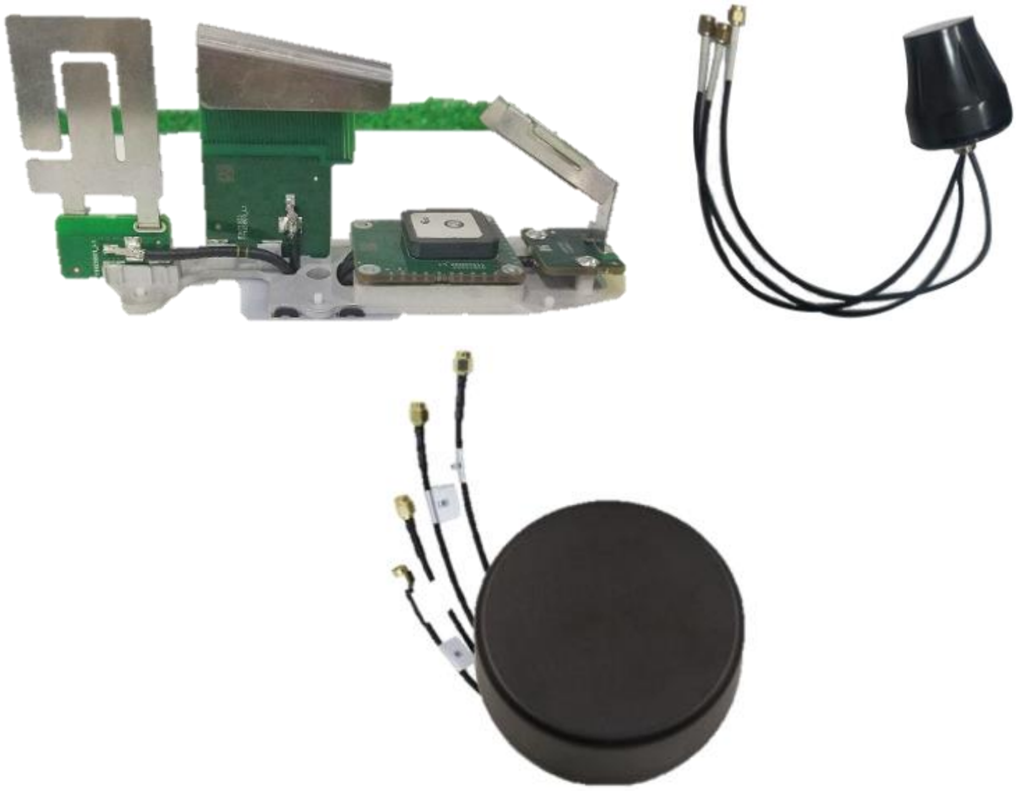


Figure 12: All-In-One antenna

Notes:
1. This type of antennas is of many models, wide frequency band coverage and are easy to be replaced.
2. The antenna combo may comprise PCB antenna, FPC antenna, metal sheet antenna, etc.
3. Frequency can be divided for the antenna port depending on various demands. The lower the required frequency is, the more the number of antennas and the larger the required size should be.
4. The antenna needs to be selected accordingly when it is installed on a metal surface.
5. The length of the antenna cable directly affects the antenna performance, thus, it is recommended to choose low-loss cable when the external distance to the antenna is long.

4.4. Sleeve Antenna

Figure 13: Example of Sleeve Antennas

Notes:
1. Sleeve antennas are available in a great variety of models. They typically support a wide operating frequency range and are easy for replacement.
2. They can be fabricated in various form such as PCB, copper pipe, and FPC.
3. The antenna model selection depends on particular operating environments.
4. With appropriate stands, sleeve antennas can be transformed into sucker antennas.

5 Embedded GNSS Antennas

5.1. Embedded Active GNSS Antenna

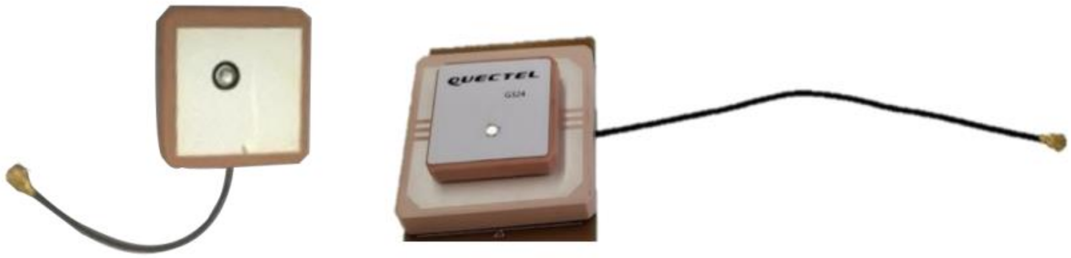


Figure 14: Example of Embedded Active GNSS Antenna with Single Feed

Notes:
1. The active antenna has a built-in LNA to improve signal strength. Please keep the antenna's radiation surface facing towards open sky.
2. Please make sure the heights of metal components nearby are lower than the antenna.
3. Square-shaped antenna is of RHCP, while rectangle-shaped antenna is of linear polarization. And the former is preferred for better satellite signal receiving.
4. Please keep the antenna cable as short as possible, and low-loss cables are recommended.
5. It is necessary to reserve LNA power supply circuit on the motherboard and a blocking capacitor should be reserved to block DC. Inductors of above 56 nH should be applied in series between the power supply and the impedance line.

5.2. Embedded Passive GNSS Antenna

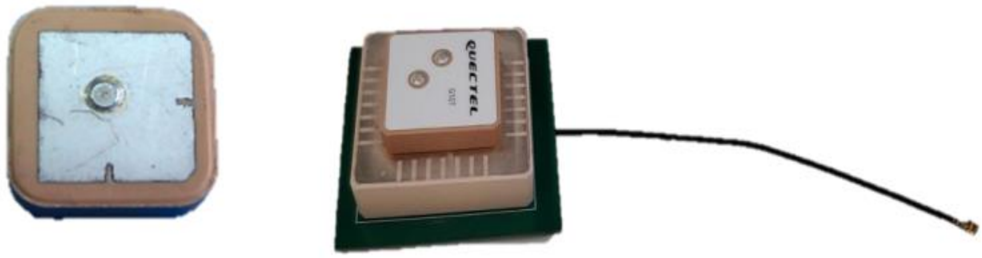


Figure 15: Example of an Embedded Passive GNSS Antenna

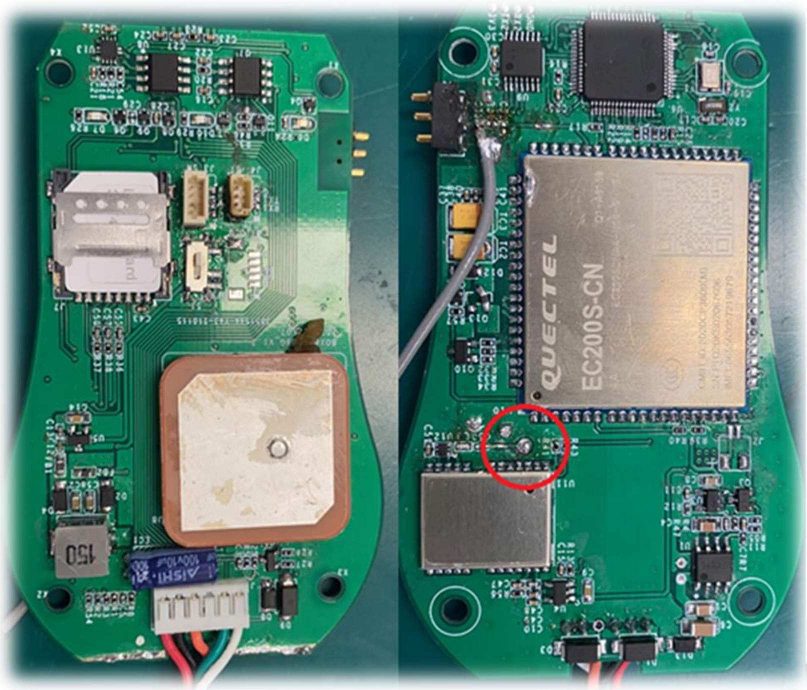


Figure 16: Application of Passive GNSS Antenna with Single Feed

Notes:
1. For passive antennas, LNA can be added on the motherboard to improve signal strength. Please keep the antenna radiation surface towards open sky.
2. Please make sure the heights of metal components nearby are lower than the antenna.
3. Square-shaped antenna is of RHCP, while rectangle-shaped antenna is of linear polarization. And the former is preferred for better satellite signal receiving.

6 External GNSS Antenna

Figure 17: Example of External GNSS Antennas

Notes:
1. Please keep the antenna radiation surface facing towards open sky.
2. The antenna should be placed away from high metal components and with sufficient clearance.
3. The length of antenna cable should be selected according to particular applications. Please keep the cable as short as possible.
4. The LNA gain may vary with different modules.
5. It is necessary to reserve LNA power supply circuit on the motherboard and a blocking capacitor should be reserved to block DC. Inductors of above 56 nH should be applied in series between the power supply and the impedance line.

7 Internal Wi-Fi Laminated Antenna

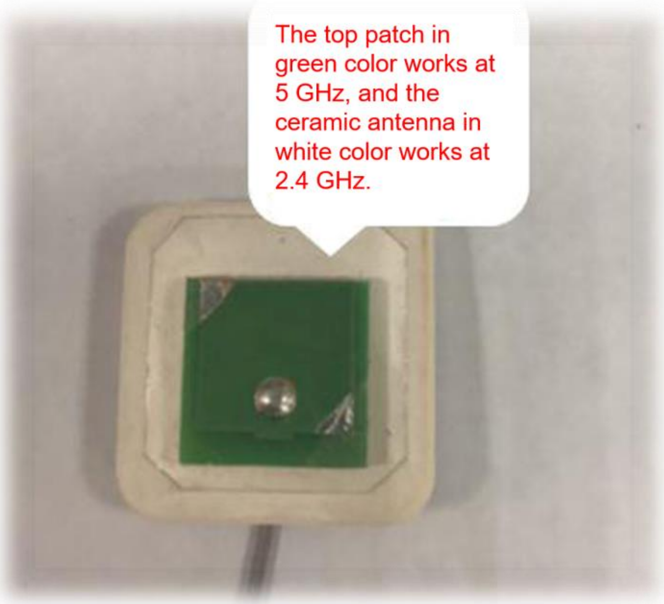


Figure 18: Example of an Internal Wi-Fi Laminated Antenna

Notes:
1. This type of antenna typically works at 2.4 GHz and/or 5 GHz operating bands. As a type of directional antenna, they can radiate or receive greater power in required directions for increased performance. The distance between the antenna and motherboard is preferred to be 20 mm.
2. The antenna should be placed away from high metal components and with sufficient clearance.
3. The patch antenna in green color works at 5 GHz, and the ceramic antenna in white color works at 2.4 GHz. The polarization design for the two antennas should be the same as that for the transmitting antenna.
4. The antenna cable length should be selected according to particular applications. Please keep the cable as short as possible and low-loss cables are recommended.

8 Requirements for Antenna Isolation Design

8.1. Antenna Isolation

For two or more antennas with overlapping frequency bands in space, antenna isolation is defined as the ratio of a signal received by one antenna to the signal transmitted by another antenna. The isolation depends on the radiation pattern of the antenna, the spatial distance of the antennas, etc. Antenna isolation improvement is to take measures to minimize the impact of various interference on the receiver.

The isolation between antennas can be increased by:

- Increasing the physical separation between the antennas
- Placing antennas working in adjacent bands orthogonally to each other
- Having the antenna's peak radiation in different or opposite directions
- Changing the antenna trace implementation method (such as length, width)

Additionally, adding a filter in the RF signal path will help to improve the desired signals’ suppression effect on those unwanted signals, thus abating the interference caused by insufficient antenna isolation.

8.2. Isolation Between 3G/4G/5G Antenna and GNSS Antenna

- The isolation between a 3G/4G/5G antenna and a GNSS active antenna should be at least 10 dB.
- The isolation between a 3G/4G/5G antenna and a GNSS passive antenna should be at least 15 dB.

It is recommended to add a filter between the module and the GNSS antenna to suppress interference from other antennas.

8.3. Isolation Design of Other Antennas

- The isolation of other antennas should be at least 15 dB.
- For simultaneous operation of multiple systems, the antenna isolation should refer to the recommended values in the module’s hardware operation manual.
- Isolation design is vital to antennas working at similar frequencies. When two antennas are used synchronously, one of them is recommended to be designed to support only part of the bands to ensure better performance.
  For example, for a device supporting GSM B1/B3/B5/B8 & LTE B1/B3/B7, the main antenna should support all the bands while the diversity antenna only needs to support LTE bands.

9 Antenna Design Service

Quectel antenna design service team will be able to meet the following demands:

- Design consulting/evaluation
- Antenna design/testing
- Certification support
- Antenna manufacturing

For any antenna design issue, please contact your local Quectel Sales or FAE.

10 Appendix A Terms and Abbreviations

Table 3: Terms and Abbreviations

Abbreviation	Description
APIP	Antenna Port Input Power
CPU	Central Processing Unit
DC	Direct Current
EIRP	Effective Isotropic Radiated Power
ERP	Effective Radiated Power
FAE	Field Application Engineer
FPC	Flexible Printed Circuit
GND	Ground
GNSS	Global Navigation Satellite System
LDS	Laser Direct Structuring
LHCP	Left-Hand Circular Polarization
LNA	Low-Noise Amplifier
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
PEIRP	Peak Effective Isotropic Radiated Power
RF	Radio Frequency
RHCP	Right-Hand Circular Polarization

SDRAM	Synchronous DRAM (Dynamic Radom Access Memory)
SMD	Surface-Mount Device
VSWR	Voltage Standing Wave Ratio