QUECTEL BG96 ANALYSIS AND COMPARATIVE STUDY WITH CAVLI C42QM

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1. INTRODUCTION

The Quectel BG96 is a Low Power Wide Area (LPWA) module used in a variety of IoT applications. It supports multiple network technologies which are LTE Cat M1, LTE Cat NB1, and EGPRS (2G fallback).

The BG96 stands for:

Term	Meaning
B	LPWA Product Family
G	GSM/EGPRS (2G) Support
96	Product Series Number

2. PRODUCT CONCEPT

2.1. GENERAL OVERVIEW

The Quectel BG96 is a low-power, compact, embedded wireless communication module designed for IoT applications. It supports LTE Cat M1, LTE Cat NB1, and EGPRS standards, ensuring reliable data connectivity across a range of network environments. Its ability to operate on LTE-TDD, LTE-FDD, and 2G networks provides extensive coverage and flexibility. Half-duplex LTE operation minimizes power consumption while supporting bi-directional data. Optional GNSS functionality (GPS, GLONASS, BeiDou) enables location tracking, making it suitable for M2M applications like smart metering, asset tracking, and wireless payment systems.

2.2. KEY FEATURES

PHYSICAL FEATURE

Its compact size (26.5mm × 22.5mm × 2.3mm) and weight (~3.1g) make it ideal for embedded and space-constrained applications. The 102-pin LGA form factor ensures secure mounting and helps minimize parasitic inductance and EMI exposure in RF routing.

TEMPERATURE RANGE

The BG96MA-128-SGN module supports a wide range of temperature conditions, making it suitable for industrial and outdoor IoT applications. Its **operating temperature range** is from **-35°C to +75°C**, within which the module performs fully compliant with **3GPP standards**. The **extended temperature range**, from **-40°C to +85°C**, allows the module to continue functioning without failure—it can still handle voice, SMS, data, and emergency calls—but some performance parameters like output power (**Pout**) may temporarily drift beyond typical tolerances. However, there's no permanent damage or impact on the radio network. Once the temperature returns to the normal range, the module fully regains 3GPP compliance. Additionally, it has a **storage temperature range** of **-40°C to +90°C**, ensuring the device remains safe and undamaged even during non-operational periods in harsh environments.

POWER SUPPLY

The module operates between 3.3V and 4.3V, with a typical voltage of 3.8V, making it ideal for power-sensitive and battery-operated IoT applications.

TRANSMITTING POWERS

Band	**Power Class**	**Transmit Power**	**Use Case**
LTE-FDD/TDD	Class 3	23 dBm (200 mW)	Standard LTE IoT connectivity
GSM850/900	Class 4	33 dBm (2 W)	Long-range legacy support
DCS1800/1900	Class 1	30 dBm (1 W)	Urban GSM coverage
GSM850/900 8-PSK	Class E2	27 dBm (500 mW)	EDGE high-speed data
DCS/PCS 8-PSK	Class E2	26 dBm (400 mW)	EDGE in high-frequency bands

LTE FEATURES

The BG96MA-128-SGN module supports both LTE Cat M1 and LTE Cat NB1, which are low-power wide-area (LPWA) technologies optimized for IoT applications. LTE Cat M1 uses a wider 1.4 MHz bandwidth, offering higher data rates of up to 375 kbps in both downlink (DL) and uplink (UL). LTE Cat NB1, on the other hand, uses a narrower 200 kHz bandwidth, making it more power-efficient and better suited for very low data rate applications, with peak speeds of 32 kbps DL and 70 kbps UL. The module also supports Single Input Single Output (SISO) in the downlink direction, which simplifies antenna requirements and further reduces power consumption—ideal for battery-operated IoT devices.

GSM FEATURES

The BG96MA-128-SGN module supports GSM features through both GPRS and EDGE technologies for 2G connectivity. In GPRS mode, it supports multi-slot class 33, enabling simultaneous transmission and reception, with coding schemes CS-1 to CS-4 and data rates of up to 107 kbps (downlink) and 85.6 kbps (uplink). For higher data speeds, EDGE is supported with the same multi-slot class 33 and uses both GMSK and 8-PSK modulation to accommodate various modulation and coding schemes (MCS 1-9), achieving up to 296 kbps (DL) and 236.8 kbps (UL). The main difference between GPRS and EDGE is that EDGE uses advanced modulation (8-PSK) for faster data rates, while GPRS uses simpler GMSK modulation. This dual support allows flexible fallback options when LTE is unavailable, ensuring reliable data transmission in legacy GSM networks.

INTERNET PROTOCOL FEATURES

The BG96MA-128-SGN module supports a wide range of internet protocols, enabling robust and flexible data communication for IoT applications. It includes standard protocols like **PPP**, **TCP**, and **UDP** for basic data transmission, while **SSL/TLS** ensures secure encrypted communication. For file and web services, it supports **FTP(S)** and **HTTP(S)**, allowing secure file transfer and web interactions. **NITZ** provides automatic network time synchronization, and **PING** is used for connectivity checks. **MQTT**, a lightweight messaging protocol ideal for IoT, is also supported. Additionally, the module supports **PAP** and **CHAP** authentication protocols, commonly used in PPP connections, ensuring secure user verification and session control during internet access.

(U)SIM INTERFACE AND SMS

The BG96MA-128-SGN module supports SMS functionality in both **Text** and **PDU (Protocol Data Unit)** modes, allowing flexibility in message formatting and encoding. It enables **point-to-point mobile-originated (MO)** and **mobile-terminated (MT)** SMS, meaning it can both send and receive text messages. It also supports **SMS cell broadcast**, which is useful for sending messages to multiple users in a specific area. For storage, SMS messages are saved in the **Mobile Equipment (ME)** memory by default. Additionally, the module supports both **USIM and SIM cards** operating at **1.8V and 3.0V**, ensuring compatibility with a wide range of cellular networks and devices.

AUDIO FEATURE

The BG96MA-128-SGN module features a **digital audio interface via PCM (Pulse Code Modulation)**, intended for voice-capable IoT applications. This interface allows the exchange of digitized voice data with external audio codecs using a standard 4-wire PCM configuration. It supports various bit rates and formats for flexible integration. However, it’s important to note that **this feature is still under development** and may not be fully available in all firmware versions. Once implemented, it will enable basic voice functions alongside data communication.

USB INTERFACE

The BG96MA-128-SGN module includes a **USB 2.0 interface (slave-only)** that supports data transfer rates of up to **480 Mbps**. It is used for **AT command communication**, **data transmission**, **GNSS NMEA output**, **software debugging**, and **firmware upgrades**. The module is compatible with USB serial drivers for major operating systems, including **Windows (7 to 10)**, **Linux (3.4 and later)**, and **Android (4.x to 9.x)**, ensuring wide platform support and easy integration.

UART INTERFACES

Quectel BG96 Analysis

The BG96 module includes three UART interfaces, each with a specific role: UART1 for AT commands and data, UART2 for debugging, and UART3 for GNSS output. All operate at 115200 bps, making them easy to integrate.

UART	Purpose	Baud Rate	Notes
UART1	AT commands & data transmission	115200 bps	Default 8N1 format, supports RTS/CTS flow control
UART2	Debugging & log output	115200 bps	Used for monitoring and troubleshooting
UART3	GNSS data (NMEA output)	115200 bps	Outputs location data in NMEA format

AT COMMANDS

The BG96MA-128-SGN module supports standard **AT commands** based on **3GPP TS 27.007** and **3GPP TS 27.005**, which are used for controlling mobile network functions like SMS, call handling, and network registration. In addition, it includes **Quectel enhanced AT commands**, which provide extended functionality specific to the module, such as power saving, GNSS control, and IoT-specific features. These commands allow easy configuration, control, and monitoring of the module through serial communication.

NETWORK INDICATION

The BG96MA-128-SGN has a **NETLIGHT pin** that visually indicates the module's **network status** using blinking patterns, helping users quickly check connectivity without needing extra tools.

ANTENNA INTERFACES

The BG96MA-128-SGN features two distinct antenna interfaces to support both communication and positioning functions:

1. **ANT_MAIN (Main Antenna Interface):**
   This is the primary RF interface used for **cellular communication** over LTE Cat M1, LTE Cat NB1, and GSM networks. It is typically connected to an external antenna via a 50-ohm RF trace or connector (like U.FL) on the PCB. Proper layout and impedance matching are essential to ensure low signal loss and efficient radiation. The ANT_MAIN interface supports all transmission and reception activities for mobile network access.
2. **ANT_GNSS (GNSS Antenna Interface):**
   This is a dedicated RF interface for **GNSS (Global Navigation Satellite System)** reception, including GPS, GLONASS, BeiDou, Galileo, and QZSS signals. It also follows a 50-ohm RF design standard. To maintain good sensitivity and positioning accuracy, this interface is often connected to a passive or active GNSS antenna. If an active antenna is used, proper

power supply and filtering must be implemented to avoid interference with the main RF system.

FIRMWARE UPGRADE

The BG96MA-128-SGN module supports **firmware upgrades** through two main methods: **USB** and **DFOTA (Device Firmware Over-The-Air)**.

- **USB firmware upgrade** allows developers to update the module's firmware using a wired connection via the USB 2.0 interface. This method is typically used during development, debugging, or when the device is physically accessible.
- **DFOTA** enables remote firmware updates over the cellular network. This is especially useful for deployed IoT devices, as it eliminates the need for physical access. It ensures devices can stay up-to-date with new features, security patches, or bug fixes.

Both methods are essential for maintaining **long-term stability**, **security**, and **performance** of the device, especially in large-scale or remote IoT deployments.

RoHS

The BG96MA-128-SGN module is fully **compliant with the EU RoHS (Restriction of Hazardous Substances) directive**, which means all its hardware components are manufactured without using hazardous materials like lead, mercury, cadmium, and certain flame retardants. This ensures the module is environmentally friendly and safe for use in electronic products sold in Europe and other RoHS-regulated regions

2.3 Supported Network Technologies

LTE Cat M1 (LTE-M)

LTE Cat M1 is a 4G technology optimized for IoT. It balances data rate, power efficiency, and latency. With support for mobility and VoLTE for voice, it's suitable for mobile IoT devices such as wearables, asset trackers, and smart meters.

LTE Cat NB1 (NB-IoT)

NB-IoT is a narrowband radio technology focusing on low power consumption and long-range communication. It is ideal for stationary IoT devices like utility meters and environmental sensors which does not require frequent data transfer.

EGPRS (2G)

Enhanced GPRS or EDGE, is a 2G technology providing basic mobile data services. it is used as a fallback option when LTE coverage is unavailable.

Frequency Band Support

LTE Bands (Cat M1/NB1)

The BG96 supports a wide range of LTE Frequency Division Duplex (FDD) bands, which enables it to be used globally.

The LTE bands supported are:

Band	Frequency Range (MHz)	Typical Region
B1	2100	Asia, Europe
B2	1900	North America
B3	1800	Europe, Asia
B4	1700/2100	North America
B5	850	Global
B8	900	Europe, Asia, Oceania
B12	700	North America
B13	700	North America
B18	850	Japan
B19	850	Japan, Korea
B20	800	Europe
B25	1900+	North America
B26	850+	North America, Japan
B28	700 APT	Asia Pacific, South America

EGPRS Bands

EGPRS operates on the globally accepted GSM bands. The supported 2G bands are:

- 850 MHz, 900 MHz, 1800 MHz, 1900 MHz

Technical Summary

Technology	Max DL	Max UL	Frequency Bands	Notes
Cat M1	375 kbps	375 kbps	B1–B5, B8, B12–B13, B18–B20, B25–B26, B28	Supports VoLTE
Cat NB1	32 kbps	70 kbps	Same as Cat M1	Ultra low power
EDGE	296 kbps	236.8 kbps	850/900/1800/1900 MHz	2G fallback
GPRS	107 kbps	85.6 kbps	Same as EDGE	Backup network

Voice Services

The Quectel BG96 supports Voice over LTE (VoLTE) functionality on LTE Cat M1 networks. This allows the device to make and receive high-quality voice calls over LTE without the need for 2G or 3G networks.

VoLTE (Voice over LTE)

VoLTE enables voice communication over a 4G LTE data connection. It is available only on LTE Cat M1, and not supported on Cat NB1 or EGPRS. Benefits include improved voice clarity, faster call setup times, and simultaneous voice and data usage.

SMS Services

The BG96 module provides support for SMS on LTE Cat M1, Cat NB1, and EGPRS networks. This ensures communication capabilities even in low bandwidth or fallback network conditions.

Point-to-Point SMS

This is the standard method for sending and receiving SMS messages between two endpoints.

- MO (Mobile Originated): Sending SMS from the device to another phone number or server.
- MT (Mobile Terminated): Receiving SMS sent to the module from another number or server.

Cell Broadcast SMS

Cell broadcast is a method for sending messages to all devices within a specific geographical area. It is widely used for emergency alerts and public information.

SMS Message Formats

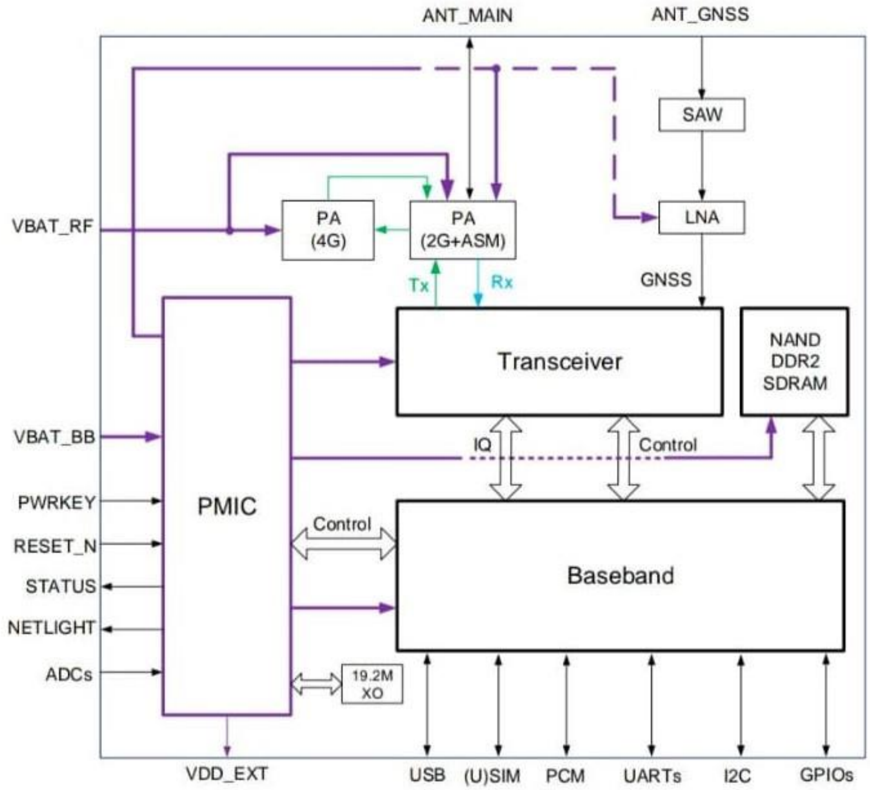
BG96 supports two SMS formats:
- Text Mode: Human-readable messages suitable for debugging and manual testing. Easy to use and debug using AT commands.

Quectel BG96 Analysis
- PDU Mode: Encoded messages in hexadecimal format, preferred for embedded and automated systems.

Summary: SMS and Voice Support Across Networks

Feature	Cat M1	Cat NB1	EGPRS
VoLTE	Yes	No	No (2G voice only)
SMS (MO & MT)	Yes	Yes	Yes
Cell Broadcast SMS	Yes	Yes	Yes
Text Mode SMS	Yes	Yes	Yes
PDU Mode SMS	Yes	Yes	Yes

2.4 Functional Diagram Overview



The major functional parts are:

- Power Management
- Baseband
- DDR + NAND Flash Memory
- Radio Frequency (RF)
- Peripheral Interfaces

PMIC (Power Management IC)

- Handles the distribution of power within the module.
- Takes input from:
  - `VBAT_RF`: Voltage supply for RF components.
  - `VBAT_BB`: Voltage supply for baseband (digital) components.
  - `PWRKEY`, `RESET_N`, `STATUS`, `NETLIGHT`: Used to manage power states and system status.
  - `ADCs`: Analog input signals monitored by the PMIC.
  - `19.2M XO`: External crystal oscillator input to generate clocks.
- Outputs `VDD_EXT` (external power output) and controls the Baseband and Transceiver.

Baseband

- It is the digital brain of the module.
- Handles:
    - Signal processing
    - Protocol stack
    - Interface control
- Communicates with:
    - Transceiver using `IQ` (In-phase and Quadrature) and `Control` signals.
    - Memory (NAND + DDR2 SDRAM).
    - External interfaces:
        - `USB`, `(U)SIM`, `PCM` (for voice/audio), `UARTs`, `I2C`, and `GPIOs`.

Transceiver

- Converts baseband signals to RF signals and vice versa.
- Controls:
    - Power Amplifiers (PA) for:
        - 4G
        - 2G + ASM (Antenna Switch Module)
    - Sends Tx signals to antennas.
    - Receives Rx signals from antennas.
    - Interfaces with SAW (Surface Acoustic Wave) filter and LNA (Low Noise Amplifier) for GNSS (GPS).

RF Path

- ANT_MAIN: Main antenna port (used for LTE/2G Tx and Rx).
- ANT_GNSS: GNSS antenna port for GPS signals.
- Signals are passed through:
    - SAW filter (cleans GNSS signals)
    - LNA (boosts weak GNSS signals before sending to Transceiver)

Memory

- NAND Flash + DDR2 SDRAM: Stores firmware, OS, and working memory for processing.

External Interfaces

- USB: Communication/debugging interface
- (U)SIM: SIM card interface
- PCM: Audio interface (for voice)
- UARTs: Serial communication
- I2C: For sensors/ICs

- GPIOs: General purpose input/output pin

3.1 Antenna Interfaces

The BG96 features a dedicated RF pin for the main cellular antenna, known as ANT_MAIN, which is located at Pin 60 of the module. This pin is the primary connection point for transmitting and receiving RF signals to and from the cellular network. The ANT_MAIN pin is designed to have a characteristic impedance of 50 ohms, which matches the standard impedance of most RF systems, cables, and antennas. This impedance matching is critical to ensure minimal signal reflection, reduced transmission loss, and efficient power transfer between the module and the antenna.

This antenna interface is intended to be used for LTE Cat M1, LTE Cat NB1, and GSM/EGPRS connectivity, and forms one of the most essential external connections for ensuring that the module can communicate wirelessly in deployed applications such as smart meters, asset tracking systems, and industrial monitoring devices.

3.1.1 Pin Definition

The ANT_MAIN interface is explicitly defined on Pin 60. This pin is both an input and output (I/O) as it handles both transmission and reception of RF signals. Its electrical characteristic is a fixed 50-ohm impedance, which must be preserved throughout the entire RF path — including PCB trace, connectors, and the external antenna — to ensure optimal signal integrity. Poor impedance matching may lead to voltage standing wave ratio (VSWR) issues, reduced transmission efficiency, and unwanted heating of RF components.

The document recommends leaving the pin unconnected only if the RF functionality is not needed — which is rarely the case in practical IoT applications. In nearly all scenarios, an external antenna is connected through this pin to facilitate wireless data exchange.

3.1.2 Operating Frequency

The Quectel BG96 module is designed to operate across a broad range of cellular frequency bands, making it highly adaptable for global IoT deployments. It supports both LTE and GSM technologies, allowing a single hardware platform to function across diverse carrier networks.

For LTE-FDD, the BG96 covers bands B1, B2, B3, B4, B5, B8, B12, B13, B18, B19, B20, B25, and B28, with B26 under development. These bands are widely used across North America, Europe, and Asia. In LTE-TDD, only Band 39 is supported and is available exclusively for Cat M1, commonly used in China. This broad coverage ensures the module's compatibility with most LTE networks worldwide.

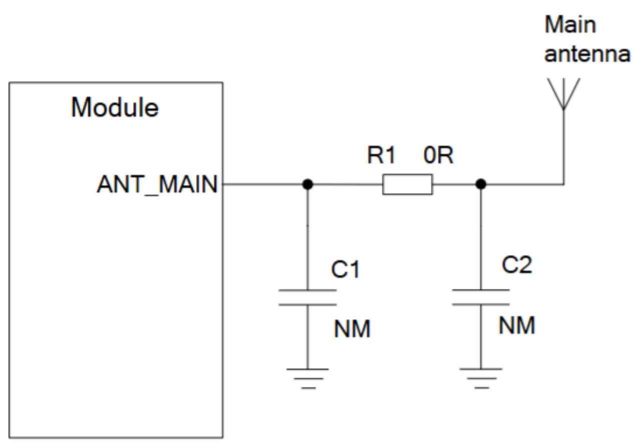
3GPP Band	Transmit	Receive	Unit
LTE-FDD B1	1920~1980	2110~2170	MHz
LTE-FDD B2, PCS1900	1850~1910	1930~1990	MHz
LTE-FDD B3, DCS1800	1710~1785	1805~1880	MHz
LTE-FDD B4	1710~1755	2110~2155	MHz
LTE-FDD B5, GSM850	824~849	869~894	MHz
LTE-FDD B8, EGSM900	880~915	925~960	MHz
LTE-FDD B12	699~716	729~746	MHz
LTE-FDD B13	777~787	746~756	MHz
LTE-FDD B18	815~830	860~875	MHz
LTE-FDD B19	830~845	875~890	MHz
LTE-FDD B20	832~862	791~821	MHz
LTE-FDD B25 [1)]	1850~1915	1930~1995	MHz
LTE-FDD B26*	814~849	859~894	MHz
LTE-FDD B28	703~748	758~803	MHz
LTE-TDD B39	1880~1920	1880~1920	MHz

The module also supports legacy GSM/EGPRS bands, including GSM850, EGSM900, DCS1800, and PCS1900, providing reliable connectivity in areas with limited LTE availability. This backward compatibility makes the BG96 suitable for mission-critical applications where network availability is unpredictable.

To ensure optimal performance, the antenna connected to the main interface must support all required frequency bands. Typically, multi-band or wideband antennas are used to meet this need, though matched antennas may be selected for specific regional deployments. Overall, the wide operating frequency range of the BG96 ensures its global versatility and robust wireless performance in a wide array of IoT use cases.

3.1.3 Reference Design of RF Antenna Interface

To ensure optimal RF performance, Quectel provides a reference design for the RF antenna interface. The design includes a π-type matching network, consisting of passive components (inductors and capacitors) arranged to match the impedance between the antenna and the module. Proper matching ensures that the majority of the RF energy is radiated through the antenna and not reflected back into the module, which could cause interference or power loss.



The π-network also provides flexibility in tuning for different frequency bands and antenna types. Quectel suggests populating the matching network with appropriate component values after antenna tuning and testing using a vector network analyzer (VNA).

Additionally, TVS (Transient Voltage Suppression) diodes are recommended in the reference design to protect the RF front end from ESD (Electrostatic Discharge). These diodes help prevent damage due to static electricity, especially in cases where the antenna may be exposed to physical contact or placed near external connectors. The placement of these diodes should be as close as possible to the antenna connector for maximum effectiveness.

All passive components should be placed tightly around the ANT_MAIN pin with short, wide traces to reduce parasitic inductance and improve signal quality. RF simulation tools and real-world validation are strongly encouraged during the prototyping phase.

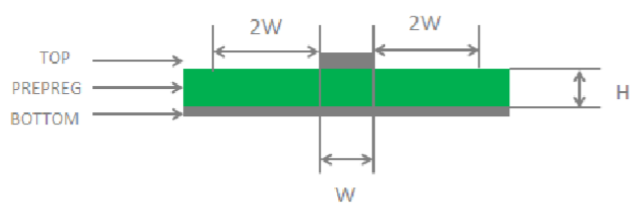
3.1.4 Reference Design of RF Layout

RF layout is a critical part of any wireless design. Even with the best component selection, poor PCB layout can lead to high losses, unwanted emissions, and regulatory failures. In this section, Quectel outlines the best practices for routing the RF trace between the module and the external antenna connector.

Designers can choose between microstrip and coplanar waveguide (CPWG) structures depending on the PCB layer stack and application. Both structures are aimed at maintaining a 50-ohm controlled impedance along the RF trace:

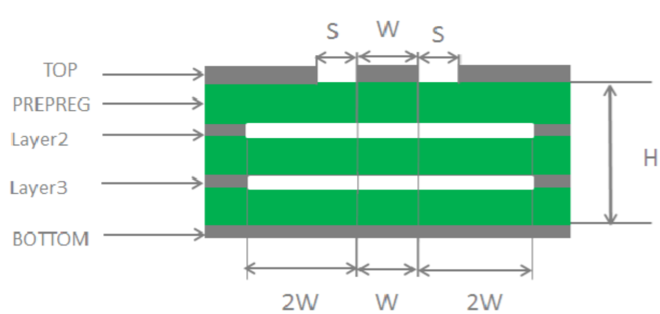
Microstrip Line (2-layer PCB)

- The RF signal trace is routed on the top layer, with a solid ground plane below.
- The trace width and dielectric height must be calculated using impedance formulas or simulation tools.
- Ground vias must be placed along the RF trace to minimize return path loop area and reduce radiation.



Coplanar Waveguide (CPWG) (2-layer or 4-layer PCB)

- The RF trace is surrounded by ground traces on both sides on the same layer.
- This layout provides better EMI shielding and tighter impedance control, especially useful in noisy environments.
- Ground stitching vias are recommended at regular intervals to maintain shielding effectiveness.



For 4-layer PCBs, Quectel shows two options:

- CPWG with Layer 3 as the reference ground
- CPWG with Layer 4 as the reference ground

Each layout recommendation includes trace dimensions and cross-sectional diagrams to assist engineers with implementation. It is also emphasized that the RF trace should be as short and straight as possible, avoiding right angles and unnecessary bends that could affect signal integrity. Additionally, it is advised to keep RF traces away from high-speed digital lines and power circuits to minimize coupling and interference.

3.2 GNSS ANTENNA INTERFACE

The GNSS Antenna Interface is the point of connection between the BG96 module and an external GPS antenna or a similar satellite system. This connection point receives signals from satellites to determine the location of those satellites.

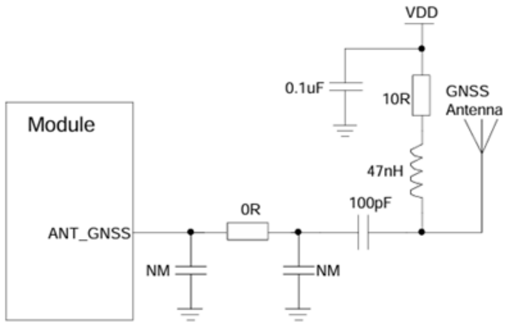
The 49th pin of the BG96 module is used as the interface and it is named as ANT_GNSS. This pin has an impedance of 50 ohm.

It supports various satellite systems such as GPS, GLONASS, Galileo, BeiDou, QZSS

Type	Frequency	Unit
GPS	1575.42±1.023	MHz
GLONASS	1597.5~1605.8	MHz
Galileo	1575.42±2.046	MHz
BeiDou	1561.098±2.046	MHz
QZSS	1575.42	MHz

The GNSS frequencies are given in the table above for each satellite. The module supports all of them under the frequency range 1559-1609 MHz even though each one has slightly different frequencies.

Reference Circuit of GNSS Antenna Interface is given below:



This circuit is used if an active GNSS antenna is used. The external V_{DD} is not required if a passive antenna is used.

3.3 ANTENNA INSTALLATION

3.3.1 ANTENNA REQUIREMENTS:

The following table shows the antenna requirements.

Antenna Type	Requirements
GNSS [1)]	Frequency range: 1559MHz ~1609MHz Polarization: RHCP or linear VSWR: < 2 (Typ.) Passive antenna gain: > 0dBi Active antenna noise figure: < 1.5dB Active antenna gain: > 0dBi Active antenna embedded LNA gain: < 17dB
LTE/GSM	VSWR: ≤ 2 Efficiency: > 30% Max Input Power (W): 50 Input Impedance (Ω): 50 Cable Insertion Loss: < 1dB (LTE B5/B8/B12/B13/B18/B19/B20/B26/B28, GSM850/EGSM900) Cable Insertion Loss: < 1.5dB (LTE B1/B2/B3/B4/B25/B39, DCS1800/PCS1900)

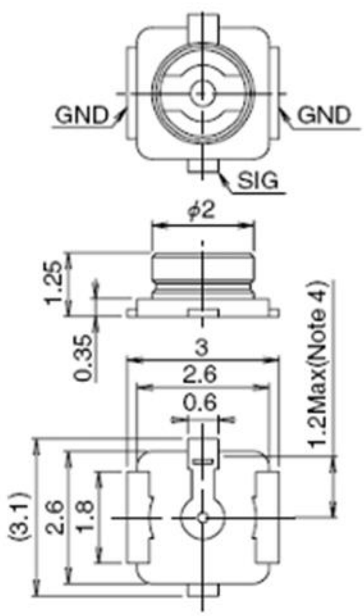
GNSS Antenna requirements: This antenna is used to receive signals from the satellites to determine the device location.
The frequency range is 1559MHz to 1609 MHz which is the GPS range. The polarization of the antenna must be RHCP (Right Hand Circularly Polarized) or linear to get clear signals. Polarisation is the way in which the signal waves spin. The Voltage Standing Wave Ratio(VSWR) must be less than 2 which indicates less signal reflection which in turn indicates better signal matching. The active and passive antennas must boost the signal whereas the LNA should not in order to reduce distortion(<17 dB).

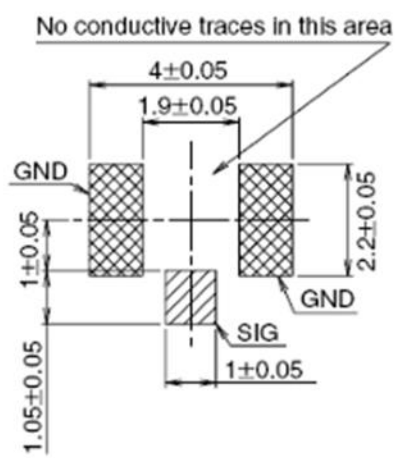
LTE/GSM Antenna Requirements: This Antenna is used to connect the module to mobile networks such as 4G or 2G.
Here also, we can see that the VSWR must be less than 2 to reduce reflection. The efficiency must be greater than 30% which means that we must be able to use more than 30 percent of the signal power, the rest of which will be lost. The maximum input power must be 50 Watt and the input impedance must be 50 ohm. The cable insertion loss must be less than 1dB or 1.5 dB which means that the signal should not be weakened much by the connection between the antenna and the module.

A passive antenna must be used if the device uses LTE band 13/14. Active antenna may generate harmonics by which the GNSS performance will be affected.

3.3.2 RECOMMENDED RF CONNECTOR FOR ANTENNA INSTALLATIONS

If we are using an RF Connector to connect the antenna to the module, it is recommended to use the U.FL-R-SMT connector. The brand HIROSE provides the above mentioned connector. Dimensions of the connector are given:





4. **RF CHARECTERISTICS**

RF (Radio Frequency) characteristics define the fundamental wireless performance of a communication module — how effectively it can transmit signals to the network and how sensitively it can receive signals from it. These parameters are not just technical specifications; they directly influence the reliability, range, penetration, and quality of wireless connectivity in real-world applications.In the context of low-power wide-area networks (LPWAN), particularly those leveraging LTE Cat M1, Cat NB1 (NB-IoT), and EGPRS technologies, two parameters are especially critical:

1. RF Output Power
2. RF Receiver Sensitivity

The Quectel BG96 is engineered with robust RF capabilities that enable it to maintain strong links even in marginal coverage areas, such as deep indoor, rural, or underground environments. It complies with 3GPP Release 13 standards and supports a wide range of LTE and GSM frequency bands, ensuring global operability and network certification readiness.One of the defining features of the BG96 is its ability to balance energy efficiency with communication reliability — delivering sufficient transmit power without significantly draining the battery, while also being able to receive weak signals with high fidelity. Additionally, the module supports antenna diversity, enhancing signal reception in mobile or interference-prone scenarios by leveraging multiple signal paths.These RF attributes make the BG96 highly suitable for critical IoT deployments where stable, long-range, and power-efficient communication is essential — including smart infrastructure, remote sensing, automotive telematics, and industrial automation.The sections that follow break down the BG96's transmit power characteristics and receiver sensitivity performance in detail, highlighting its strengths as a reliable and scalable LPWA module in today's competitive wireless module landscape.

4.1 RF OUPUT POWER

RF Output Power is defined as the power level at which the wireless module transmits data over the air, measured in dBm (decibels relative to 1 milliwatt). This parameter is critical in determining:

- Cellular uplink range (how far the module can reach the base station)
- Signal penetration through walls, enclosures, or terrain
- Battery efficiency (higher power = higher current draw)
- Compliance with telecom regulations (e.g., 3GPP TS 36.101, TS 45.005)

In IoT deployments, particularly those using Low Power Wide Area (LPWA) technologies such as LTE Cat M1 and NB-IoT (Cat NB1), a balance is needed: the module must output enough power to maintain coverage, but also preserve energy for long-term operation (e.g., 10+ years on battery).

BG96 RF Output Power Ratings

Quectel BG96 Analysis

Technology/Band	Max Output Power (dBm)	Min Output Power (dBm)
LTE-FDD (Bands B1–B28)	23dBm ± 2dB	< -39dBm
LTE-TDD (Band B39)	23dBm ± 2dB	< -39dBm
GSM850 / EGSM900	33dBm ± 2dB	5dBm ± 5dB
DCS1800 / PCS1900	30dBm ± 2dB	0dBm ± 5dB
GSM850/EGSM900 (8-PSK)	27dBm ± 3dB	5dBm ± 5dB
DCS1800/PCS1900 (8-PSK)	26dBm ± 3dB	0dBm ± 5dB

The table lists maximum and minimum RF output power across different RATs (Radio Access Technologies) and modulation schemes. These power levels define how strongly the module can transmit signals — which directly affects range, reliability, power consumption, and regulatory compliance.

1. **LTE-FDD (B1/B2/B3/B4/B5/B8/B12/B13/B18/B19/B20/B25/B26/B28)**

- Max Output Power: 23 dBm ±2 dB
- Min Output Power: < -39 dBm

  This applies to LTE Cat M1 and Cat NB1 operations using Frequency Division Duplexing (FDD). The maximum 23 dBm aligns with 3GPP Power Class 3, which is the standard for LTE-M/NB-IoT devices.

- The ±2 dB tolerance accounts for real-world conditions like temperature or hardware variation.
- The very low minimum transmit power (< -39 dBm) reflects the module's ability to adaptively reduce TX power during favourable conditions (close to tower or strong signal areas), minimizing interference and saving energy.

2. LTE-TDD (Band B39)

- Max Output Power: 23 dBm ±2 dB
- Min Output Power: < -39 dBm

This applies to Time Division Duplexing (TDD) operation for Band 39, used primarily in regions like China for NB-IoT deployments. The output power is identical to LTE-FDD operation.

- Maintaining 23 dBm ensures compliance with 3GPP standards and enables uplink reliability over long distances.
- Power control is essential in TDD to avoid self-interference, as uplink and downlink share the same frequency.

3. GSM850 / EGSM900 (GMSK modulation)

- Max Output Power: 33 dBm ±2 dB
- Min Output Power: 5 dBm ±5 dB

This is for 2G GSM operation using GMSK (Gaussian Minimum Shift Keying) modulation in low-frequency GSM bands.
33 dBm (≈ 2W) is standard for Power Class 4, used in GSM850 and EGSM900.

- These bands are designed for deep indoor and rural coverage, where low-frequency propagation is stronger.
- This high power level is essential for fallback support in regions where LTE/NB-IoT coverage is still maturing.

4. DCS1800 / PCS1900 (GMSK modulation)

- Max Output Power: 30 dBm ±2 dB
- Min Output Power: 0 dBm ±5 dB

Also 2G GSM, this time in higher-frequency bands (1800/1900 MHz). The maximum output power of 30 dBm aligns with Power Class 1.

- These frequencies have higher path loss, so the module compensates with robust transmission.
- Used commonly in urban areas or for roaming compatibility with global networks.

5. GSM850 / EGSM900 (8-PSK modulation)

- Max Output Power: 27 dBm ±3 dB
- Min Output Power: 5 dBm ±5 dB

This is for EGPRS (EDGE) operation over GSM850/EGSM900 using 8-PSK (8-phase-shift keying), a higher-order modulation that allows for increased data rates.

- Due to the linearity requirement of 8-PSK, power is reduced to 27 dBm to prevent signal distortion and comply with spectral emission limits.
- 27 dBm still ensures effective transmission while enabling EDGE use in fallback scenarios.

6. DCS1800 / PCS1900 (8-PSK modulation)

- Max Output Power: 26 dBm ±3 dB
- Min Output Power: 0 dBm ±5 dB

This covers EDGE over high-frequency GSM bands. Same reasoning applies: the lower power output (compared to GMSK) is a necessary compromise to meet ACLR (Adjacent Channel Leakage Ratio) and spectral mask requirements when using non-constant envelope modulation like 8-PSK.

4.2 RF RECEIVER SENSITIVITY

RF receiver sensitivity refers to the minimum signal strength that a wireless module can detect and reliably decode. It is measured in decibel-milliwatts (dBm), where more negative values indicate better sensitivity. This parameter is crucial for evaluating the module's ability to maintain connectivity in low-signal environments, such as deep indoors, underground facilities, or remote rural areas.

For IoT modules like the Quectel BG96, which support LTE Cat M1, Cat NB1 (NB-IoT), and GSM/EGPRS, receiver sensitivity plays a vital role in ensuring data reliability, minimal packet loss, and low power retransmissions. In practical deployments, especially in fixed or battery-operated devices, superior sensitivity reduces the need for high transmit power, conserving energy while ensuring consistent performance.The BG96 is designed to offer strong reception capabilities across a wide range of LTE and GSM frequency bands, with support for antenna diversity in many LTE bands. This diversity allows the module to use multiple signal paths for better reception, enhancing link robustness and fade resistance

BG96 RF RECEIVER SENSITIVITY

The tables below summarize the BG96's receiver sensitivity values for LTE and GSM networks, indicating how effectively the module can function under various radio conditions.

1. LTE-FDD Receiving Sensitivity

Band	Cat M1 (dBm)	Cat NB1 (dBm)	Primary	Diversity
B1	-107 / -102.7	-112.5 / -107.5	Supported	Supported
B2	-106.7 / -100.3	-112.5 / -107.5	Supported	Supported
B3	-106.8 / -99.3	-113.0 / -107.5	Supported	Supported
B4	-106.9 / -102.3	-112.5 / -107.5	Supported	Supported
B5	-107.0 / -100.8	-114.0 / -107.5	Supported	Supported
B8	-107.3 / -99.8	-113.0 / -107.5	Supported	Supported
B12	-107.7 / -99.3	-113.5 / -107.5	Supported	Supported
B13	-106.5 / -99.3	-112.0 / -107.5	Supported	Not Supported

Quectel BG96 Analysis

B18	-107.5 / -102.3	-113.5 / -107.5	Supported	Not Supported
B19	-107.1 / -102.3	-114.0 / -107.5	Supported	Not Supported
B20	-107.2 / -99.8	-114.0 / -107.5	Supported	Not Supported
B25	-106.1 / -100.3	-112.0 / -107.5	Supported	Not Supported
B26	TBD / -103	TBD / -107.5	Supported	Not Specified
B28	-107.2 / -100.8	-113.0 / -107.5	Supported	Not Supported
B39 (TDD)	TBD / -103	Not supported	Supported	Not Supported

The BG96 supports LTE-FDD operation for both Cat M1 (also known as LTE-M) and Cat NB1 (NB-IoT), over globally significant bands such as B1, B3, B5, B8, B12, B13, B18, B19, B20, and B28. Each band shows both Cat M1 and Cat NB1 sensitivity in dBm. In the LTE sensitivity table, each value is represented as <Typical Performance> / <3GPP Requirement>, where the left value indicates the BG96 module's actual measured sensitivity and the right value reflects the minimum sensitivity threshold defined by 3GPP TS 36.101.

In the LTE sensitivity table, bands such as B26 and B39 are marked as TBD (To Be Determined), indicating that the typical receiver sensitivity data has not yet been officially published by Quectel. However, the 3GPP minimum sensitivity requirement for these bands remains applicable and is typically listed alongside the TBD placeholder for reference.

Product Relevance:

- Cat NB1 achieves down to –114 dBm, aligning with 3GPP targets for extended coverage (CE Level ECL2).
- Support for antenna diversity in critical bands (e.g., B1–B12) boosts performance in environments with fading and multipath.
- Bands like B19, B20, and B28 — commonly used in Europe and Asia — are fully supported with excellent sensitivity, giving BG96 global deployment flexibility.
- Cat NB1 consistently outperforms Cat M1 in terms of raw sensitivity — reaching up to –114 dBm, which is near the theoretical limit for narrowband receivers.
- These values are measured without repetitions, indicating raw baseband performance and signaling superior RF front-end design.
- Support for antenna diversity (in primary LTE bands) helps mitigate multipath fading, crucial for real-time and mobile devices.

2. GSM Receiving Sensitivity

GSM fallback remains essential for modules intended for multi-region deployments, particularly in areas where LTE or NB-IoT is not yet widely available. In the GSM sensitivity table, the two values shown in the <Typical> / <3GPP Limit> format represent the measured receiver sensitivity of the BG96 module and the 3GPP-defined minimum performance level as per TS 45.005.

Quectel BG96 Analysis

Band	Sensitivity (dBm)	Primary	Diversity
GSM850 / EGSM900	-109 / -102	Supported	Not Supported
DCS1800 / PCS1900	-108.5 / -102	Supported	Not Supported

Product Relevance:

- With sensitivity values near -109 dBm, BG96 can operate in areas with weak GSM signal strength, ensuring SMS or GPRS-based fallback communication.
- Though GSM does not support diversity in BG96, the baseline performance is competitive with other LPWA modules still relying on 2G fallback.
- This makes BG96 suitable for dual-stack deployments, where LTE is the primary, and GSM is the backup connectivity layer.

The RF characteristics of the Quectel BG96 demonstrate a well-balanced design that prioritizes both transmit efficiency and receiver sensitivity, making it a versatile and competitive choice for LPWA (Low Power Wide Area) IoT applications. With RF output power levels compliant with global 3GPP standards and receiving sensitivity that exceeds minimum requirements across multiple LTE and GSM bands, the BG96 offers excellent link budget performance, particularly in coverage-challenged environments. Support for antenna diversity in key LTE bands further enhances its ability to maintain reliable communication in the presence of multipath fading and interference. Combined with its support for fallback to 2G networks, the BG96 positions itself as a robust, global solution that meets the needs of real-world deployments requiring low power consumption, wide-area coverage, and network resilience.

5. COMPARISON WITH C42QM

The Cavli C42QM module was chosen for comparison with the Quectel BG96 because it closely matches the BG96 in terms of technology, features, and application areas. Both modules support LTE Cat M1, NB-IoT, and 2G fallback, making them suitable for low-power wide-area network (LPWAN) applications such as smart metering, asset tracking, and remote monitoring.

Our aim was to explore how these two modules perform under similar conditions and to identify any differences in integration, power efficiency, connectivity, and ease of deployment. The C42QM stood out as a suitable comparison point due to its similar network capabilities, compact design, and support for global bands. By comparing it with the widely adopted BG96, we aim to evaluate alternative solutions that offer similar performance with potential benefits in cost or integration flexibility.

Feature	Cavli C42QM	Quectel BG96-MA-128-SGN	Notes
Form Factor	LGA	LGA	Both modules utilize a compact LGA package, making them suitable for small IoT devices.
Connectivity	LTE Cat M1, NB2, EGPRS/2G	LTE Cat M1, NB1, EGPRS	The primary difference here is the NB-IoT standard supported: Cavli's C42QM uses NB2, while Quectel's BG96-MA-128-SGN uses NB1.
GNSS Support	GPS, GLONASS, BeiDou, Galileo	Yes (GPS, GLONASS, BeiDou, Galileo)	Both modules offer integrated multi-constellation GNSS for precise location tracking.
Data Rates (Peak)	Cat M1: 588 Kbps (DL), 1199 Kbps (UL); NB2: 127 Kbps (DL), 158.5 Kbps (UL); EGPRS: 236.8 Kbps (DL/UL)	Cat M1: 375 Kbps (DL/UL); NB1: 32 Kbps (DL), 70 Kbps (UL); EDGE: 296 Kbps (DL), 236.8 Kbps (UL); GPRS: 107 Kbps (DL), 85.6 Kbps (UL)	Cavli's C42QM boasts higher peak data rates, particularly for Cat M1.
Power Consumption	Ultra-low power consumption with PSM and eDRX	Ultra-low power consumption	Both are designed for low-power IoT applications and incorporate power-saving features.
eSIM	Optional integrated eSIM	Supports integrated SIM card slot, supports external SIM	The Cavli C42QM offers an optional embedded SIM,

			simplifying global connectivity management.
Interfaces	USB 2.0, UART (3x), I2C, SPI, I2S, ADC (2x), USIM, JTAG	USB 2.0, UART (3x), PCM, ADC (2x), GPIO (reconfigurable), (U)SIM	The interfaces are largely similar, catering to common IoT peripheral connections.
Supported OS	ThreadX OS	Windows, Linux, Android	Cavli specifically mentions ThreadX OS. Quectel lists broader operating system support.
Memory	32MB RAM/64MB Flash	3MB Flash/3MB RAM (user accessible)	Cavli's C42QM offers more memory.
IoT Platform Integration	Integrated with Cavli Hubble Platform	Compatible with various platforms	Cavli provides a specific platform for managing their modules. Quectel is more broadly compatible with different platforms.

In summary:

The Cavli C42QM and Quectel BG96-MA-128-SGN are both strong contenders for LPWA IoT applications requiring integrated GNSS and low power consumption.

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