GTI 5G S-Module White Paper

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Document History

Date	Meeting #	Version #	Revision Contents
Oct. 31, 2018	23rd GTI Workshop	V1.0	The first version of GTI 5G S-Module Whitepaper. The standardization status of 5G universal modules, the industry status of 5G S-Modules and the typical technology solutions for 5G S-Modules are described.
Feb.19, 2019	24th GTI Workshop	V1.1	Some revisions have been made to Section “8.2.2 Pin Layout” and “8.2.3 Pin Size” of "GTI 5G S-Module Whitepaper (v1.0)" as per the industry R&D progress. Section "8.3.2 Pin Layout" and "8.3.4 Pin Definition" have been updated. Some pins have been clarified as "/Reserved" also. Some misalignments between "8.3.2 Pin Layout" and "8.3.4 Pin Definition" have been fixed.
Jun. 21, 2019	25th GTI Workshop	V2.0	The original “5G S-Module Basic Type 1” and “5G S-Module Basic Type 2” have been merged as “5G S-Module Basic Type-L” as per the latest industry R&D progress. The original “5G S-Module Basic Type 3” has been renamed as “5G S-Module Basic Type-M”. Section “5.2.2.1 Modes and Bands” has been updated. Section “6 The Industry Status” has been updated as per the latest progress of the industry. Section “8.4 5G S-Module All-in-one Type-M”, Section “8.5 5G S-Module All-in-one Type-L” and Section “11 Typical Application Scenarios for 5G S-Module” have been added.
Nov. 1, 2019	26th GTI Workshop	V2.1	A new kind of 5G S-Module basic type-L (Layout 3) is added in section 8.1. A new kind of 5G S-Module basic type-L is added in section 8.1A. Section “6 The Industry Status” has been updated as per the latest progress of the industry. The diagram of 5G S-Module Basic Type-L in section 8.1.1 is updated. The pin layouts of 5G S-Module basic type-L in section 8.1.2 and the pin size of 5G S-Module basic type-L in section 8.1.3 are updated. The pin definition of 5G S-Module basic type-L is updated and a new pin definition of 5G S-Module basic type-L is added in section 8.1.4.

			The pin layout of 5G S-Module Basic Type-m is updated in section 8.2.2. The pin definition of 5G S-Module Basic Type-m is updated in section 8.2.4. Module power current in power off mode in section 9.1.1 is updated. Setup of ADC in section 9.6.1 is updated.
July. 21, 2020	28th GTI Workshop	V3.0	The bands and interface requirement in section 5.2.2 is updated; The Basic functions Requirements on 5G S-Module in section 7.1 is updated; The data I/O interface in section 9.5 is updated; Chapter 11 network slicing capability and Chapter 12 positioning capability are added.

Table of Contents

1 Executive Summary

This white paper provides a technical overview of the **5G Superior Universal Module**, which is known as "**5G S-Module**". It covers the industry status, the requirement, and the technology for 5G S-Module.

5G Technology has three typical scenarios: eMBB, mMTC, and URLLC, which bring a number of enhancements including ultra-high speeds, large quantity of connection, ultra-low latencies, high performance, enhanced reliability and low power consumption. eMBB brings high throughput for the 5G devices, which increases the network efficiency and performance. Our 5G S-Module will start with the application for the eMBB scenario.

In 5G network, there is a "network slicing" characteristic. It creates the possibility of tailoring mobile data services for the particular characteristics of specific users. For example, a dense grid network might prioritize low power consumption of massive terminals over connection speed; at the same time, a separate network slice on the same infrastructure could provide high-speed mobile communications for specific application. "Network slicing" will help 5G S-Module to use the network resources efficiently.

Network slicing ability for different services on the same physical networks raises the possibility of services targeted at different industrial verticals. Here we also analyze the status of the vertical market, the different requirement of the different verticals. For a particular industry, it may need specific attributes of the 5G S-Module, therefore, we categorize the requirements together and extract a generic requirement for the 5G S-Module. In general, the 5G S-Module will fulfill the requirements of different industry verticals.

The 5G S-Module solution helps the industry to finish their 5G capable device development easily, and makes it possible for a "turnkey" solution for different applications. The industries with embedded modules are always quite segmented. With 5G S-Module, it could meet the most industry requirements and operates at high-performance, benefiting from the 5G NR technology.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

[1] http://resources.mipi.org/mipi-i3c-v1-download
[2] 3GPP, TS 38.101-1, NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone.
[3] 3GPP, TS 38.101-2, NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone.
[4] 3GPP, TS 38.101-3, NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios.
[5] 3GPP, TS 38.101-4, NR; User Equipment (UE) radio transmission and reception; Part 4: Performance requirements.
[6] 3GPP, TS 38.521-1, NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Range 1 Standalone.
[7] 3GPP, TS 38.521-2, NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 2: Range 2 Standalone.
[8] 3GPP, TS 38.521-3, NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios.
[9] 3GPP, TS 38.521-4, NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 4: Performance.
[10] 3GPP, TS 38.523-1, 5GS; UE conformance specification; Part 1: Protocol.
[11] 3GPP, TS 38.523-2, 5GS; UE conformance specification; Part 2: Applicability of protocol test cases.
[12] 3GPP, TS 38.523-3, 5GS; User Equipment (UE) conformance specification; Part 3: Protocol Test Suites.
[13] 3GPP, TS 38.533, NR; User Equipment (UE) conformance specification; Radio Resource Management (RRM)
[14] GTI, GTI Sub-6GHz 5G Device Whitepaper (v3.0)
[15] GSA, LTE, 5G and 3GPP IoT Chipsets: Status Update, July 2019
[16] GSA, 5G Device Ecosystem, September 2019

3 Abbreviations

Abbreviation	Explanation
3GPP	3rd Generation Partnership Project
ACPC	Always Connected Personal Computer
ADC	Analog-to-Digital Converter
AI	Analog Input
AIO	Analog Input/ Output
AO	Analog Output
AP	Application Processor
APN	Access Point Name
APT	Average Power Tracking
AR	Augmented Reality
BD	BeiDou
BOM	Bill of Material
BP	Baseband Processor
BPF	Band-Pass Filter
BT	Blue Tooth
CCTV	China Central TeleVision
CHAP	Challenge Handshake Authentication Protocol
CMCC	China Mobile Communications Corporation
CMOS	Complementary Metal Oxide Semiconductor
CPE	Customer Premise Equipment
CPRL	CommandLine Uniform Resource Locator
CPU	Central Processing Unit
CRM	Customer relationship management
C-V2X	Cellular,vehicle-to-everything
DCC	Device Certification Criteria
DCDC	Direct Current/Direct Current
DDR	Double Data Rate
DI	Digital Input
DIO	Digital Input/ Output
DL	Down Link
DO	Digital Output
eMBB	Enhanced Mobile Broadband
EMC	Electro Magnetic Compatibility
eMBMS	Evolved Multimedia Broadcast Multicast Services
eMMC	Embedded Multi-Media Card

ET	Envelop Tracking
eUICC	Embedded Universal Integrated Circuit Card
ESD	Electro-Static Discharge
ESR	Errored Second Ratio
ETSI	The European Telecommunication Standards Institute
FBAR	thin Film Bulk Acoustic Resonator
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FEM	Front-End Module
FM	Frequency Modulation
FOTA	Firmware Over-The-Air
GCF	Global Certification Forum
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPIO	General Purpose I/O
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSA	Global mobile Suppliers Association
GSM	Global System for Mobile communications
GSMA	Global System for Mobile communications Alliance
GTI	Global TD-LTE Initiative
HPF	High-Pass Filter
HPUE	High Power User Equipment
I2C	Inter-Integrated Circuit
I2S	Integrated Interchip Sound
IF	Intermediate Frequency
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telecommunication
IMU	Inertial Measurement Unit
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union - Radio
LCC	Leadless Chip Carriers
LCD	Liquid Crystal Display
LDO	Low Dropout Regulator
LED	Light Emitting Diode
LGA	Land Grid Array
LNA	Low Noise Amplifier
LPDRAM	Low-Power Dynamic RAM
LPF	Low-Pass Filter

LTCC	Low Temperature Co-Fired Ceramic
LTE	Long Term Evolution
M2M	Machine to Machine
MCU	Micro-Controller Unit
MDC	MoDule Controller
MDIO	Management Data Interface
MIMO	Multi-input Multi-output
MIPI	Mobile Industry Processor Interface
MLCC	Multi-Layer Ceramic Chip
MNO	Mobile Network Operator
MUX	MUltipleX(er)
MWC	Mobile World Congress
NC	Not Connect
NMEA	National Electrical Manufacturers Association
NR	New Radio
NSA	Non StandAlone
OAM	Operation, Administration and Maintenance
OD	Open-Drain
ODU	Outdoor Unit
OEM	Original Equipment Manufacturer
ODM	Original Design Manufacturer
OS	Operating System
PA	Power Amplifier
PAP	Password Authentication Protocol
PC	Personal Computer
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
PCIe	Peripheral Component Interconnect express
PCM	Pulse-Code Modulation
PI	Power In
PMIC	Power Management Integrated Circuit
PMU	Power Management Unit
POS	Point Of Sales
PPS	Pulse Per Second
PTCRB	PCS Type Certification Review Board
PWM	Pulse Width Modulation
QoS	Quality of Service
R&D	Research and Development
RAM	Random Access Memory
RAN	Radio Access Network
RED	Radio Equipment Directive
RF	Radio Frequency

RFFE	RF Front-End
RGB	Red-Green-Blue
RGMII	Reduced Gigabit Media Independent Interface
ROM	Read-Only Memory
RRM	Radio Resource Management
RX	Receive
SA	StandAlone
SAW	Surface Acoustic Wave
SD	Secure Digital Memory Card
SDC	Serial Data Controller
SDIO	Secure Digital Input/Output
SHD	Super High Definition Display
SIM	Subscriber Identification Module
SMD	Surface Mount Technology
SMEs	small and medium-sized enterprises
SMS	Short Messaging Service
SoC	System-on-a-Chip
SPDT	Single Pole Double Throw
SPI	Serial Peripheral Interface
STB	Set Top Box
TD-LTE	Time Division Long Term Evolution
TDD	Time Division Duplex
TIS	Total Isotropic Sensitivity
TR	Technology Report
TRP	Total Radiated Power
TTCN	Testing and Test Control Notation
TTFF	Time to First Fix
TX	Transmit
UART	Universal Asynchronous Receiver/Transmitter
UAV	Unmanned Air Vehicle
UE	User Equipment
UHD	Ultra High Definition
UL	Up Link
URL	Uniform Resource Location
USB	Universal Serial Bus
USIM	UMTS Subscriber Identity Module
USSD	Unstructured Supplementary Service Data
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VR	Virtual Reality
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

WWAN	Wireless Wide Area Networks

4 Introduction

This whitepaper mainly focuses on the 5G S-Module and has been carried out in several sections in turn. Combined with the standardization status and the industry status of 5G S-Module, the whitepaper analyses the required basic functions, the hardware technical requirements, the electrical interface technical requirements, test & certification and the typical technical solutions for 5G S-Module. For the communication capability, please refer to the "GTI Sub-6GHz 5G Device Whitepaper". This GTI 5G S-Module Whitepaper is expected to help people to develop 5G S-Modules and to promote 5G industrial development especially in verticals. This whitepaper may also help people to know more about the standardization status and industrial status of 5G S-Module. Meanwhile, it may also help readers interested in 5G S-Modules and vertical devices to gain from the further thinking.

Sincere thanks to all the contributors and the supporters for their hard work in writing this whitepaper, so we are respectfully listing them in alphabetical order under every chapter.

- **Chapter 1 Executive Summary**
  CMCC, SIMCom
- **Chapter 2 Reference**
- **Chapter 3 Abbreviations**
  CMCC
- **Chapter 4 Introduction**
  CMCC
- **Chapter 5 The Standardization Status**
  CMCC, Quectel, Sprint
- **Chapter 6 The Industry Status**
  Fibocom, Cheerzing
- **Chapter 7 The Basic functions Requirements on 5G S-Module**
  Hisense
- **Chapter 8 The Hardware Technical Requirements on 5G S-Module**
  SIMCom, Fibocom, Quectel, CMIOT
- **Chapter 9 The Electrical Interface Technical Requirements on 5G S-Module**
  SIMCom
- **Chapter 10 The Test and Certification of 5G S-Module**
  Anritsu, CMCC, Keysight, R&S, SIMCom, Sprint
- **Chapter 11 Typical Technical Solutions for 5G S-Module**
  SIMCom, Fibocom, Quectel
- **Annex A 5G RF Component**

Qorvo, Taiyo Yuden, Murata

- **Annex B Antenna**

  Sunway

- **Annex C Sensor**

  SIMCom, Sprint

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This whitepaper will be continuously updated according to the research and development progress.

5 The Standardization Status

5.1 Motivation

5G network provides the enhanced bandwidth and helps many applications improve their performance. For example, Virtual and Augmented Reality, UHD 8K Online 360 Video, 16K VR Head Mounted Display for game and training, Connected Drones, Connected Automotive, Wireless e-Health – Remote Surgery, Wireless home entertainment – smart home gateway, Live Radio/Video Broadcasting, Smart helmet, Always-connected PC/Tablet/2-in-1 PC, Real-time UHD Video Surveillance and Robots (See more in "GTI Report on Vertical Requirements for 5G S-Modules and Devices"). Thus, 5G devices could serve the users in a much better and efficient way. The key motivations are as follows:

- The available bandwidth for the applications will be substantial
- Data throughput will be increased along with enhanced connectivity, higher user mobility and higher accuracy positioning
- The 5G devices could use 5G S-Module and work out their solution efficiently

5G networks can support a large number of high bandwidth devices. 5G is power efficient. It delivers a long mobile battery life because it has been engineered and optimized to operate over an extended period. 5G NR network with eMBB provides high bandwidth for the 5G multi-mode multi-band modules and modem end-devices, thus it will be beneficial for the 5G device vendors. For example, ACPC vendors could use 5G S-Module in their device product and solution directly. Economies of scale arise because the capacity of S-Module suppliers is essentially shared around the GTI markets and at the 5G industry level. The quicker we bridge 5G chipsets to S-Module, the better GTI 5G device ecosystem develops. Currently every module vendor designs their own wireless modules, with different size, form factor and pin definition. This is an industry wide bottleneck and we intend to improve the situation.

User-centric authentication layer on top of the existing subscription authentication is introduced to share S-Module usage. Once 5G networks are deployed, different users can share limited kinds of 5G S-Module. To improve the user experience, it would be beneficial to automatically change settings of operator deployed services according to the users' settings. This requires the user to be identified in addition to the existing identification of subscription based off S-Module SIM. Network settings can be adapted and services offered to users according to their user identities, independent of the subscription that is used to establish the connection [TR22.904]. Using network resource slicing technology, application aware user experience could be delivered to all user identities shared the same S-Module gateway simultaneously [TR 23.727].

5.2 Standardization of 5G S-Module

5.2.1 The Diagram of 5G S-Module

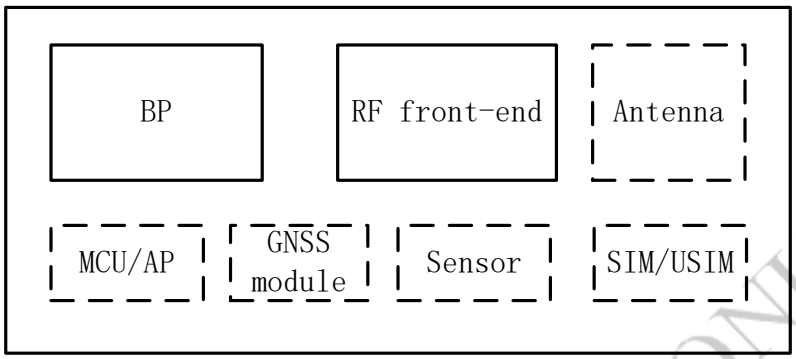


Figure 5-1 Diagram of 5G S-Module

Basic logical structure of 5G S-Module which is mainly composed of BP and RF front end is shown in Figure 5-1. 5G S-Module can also include antenna, MCU/AP, GNSS module, Sensor and SIM/USIM in terms of its different uses and functions.

5.2.2 The Key Points to classify 5G S-Module

To facilitate 5G device developments, we define modes, bands, data rate, size, form factor, weight, interface, AP/MCU, and antenna of the 5G S-Module. Considering requirements from different applications, 5G S-Modules have been divided into two major categories: Basic Type-L and Basic Type-M without high-performance processor, Smart Type with high-performance processor, Basic Type-L with LGA form factor, Basic Type-M with M.2 form factor, and All-in-one Type with built-in antennas.

5.2.2.1 Modes and Bands

The 5G S-Module may be a series of modules, depending on how many modes and how many bands it supports. The modes and bands specification are as follows:

5G NR Bands:

Mandatory: n41, n79, n78, n71, n25, n66

Optional: n77

LTE FDD Bands:

Mandatory:B1,B3,B8, B71, B66

Optional: B4, B5, B7, B12, B17, B20

TD-LTE Bands:

Mandatory: B39

Optional: B34, B40, B41

5.2.2.2 Data Rate

Date rate requested for 5G NR Sub 6GHz Module:

SA Mode (5ms single cycle frame structure, 2T4R):

1) DL peak rate: 1.7 Gbps

2) UL peak rate: 190 Mbps

Note: 5G NR bandwidth 100 MHz

5.2.2.3 Size and Form Factor

The 5G S-Module may be a series of modules, depending on different size.

1) Package Dimension (LGA):

   LGA form factor module can be applied to most of the eMBB and IoT applications, such as CPE, STB, Laptop, Tablet, and Telematics. It is also the most widely used form factor in current 4G module industry.

2) Package Dimension (LGA+LCC)

   LGA+LCC form factor module can be applied to almost all the applications for its flexibility, and sometimes it can greatly simplify the design of module and external applications.

3) Package Dimension (M.2):

   M.2 form factor follows the definition of PCI Express M.2 Specification. It provides plug-in module solution for the end-device manufacturers.

5.2.2.4 Weight

Weight: less than 10g.

The consumer application such as AR/VR always prefer low weigh components. According to the weight of PCB, chips and other components in the module, the total weight of the 5G S-Module should be less than 10 g.

5.2.2.5 Interface

- (U)SIM interface:

The (U)SIM interface circuitry meets ETSI and IMT-2000 requirements. Either 1.8 V or 3.0 V (U)SIM cards are supported.

- USB 3.1(Optional)/3.0/2.0 interface:

5G S-Module provides one integrated Universal Serial Bus (USB) interface which complies with the USB 3.1/3.0/2.0 specifications. It supports SuperSpeed+ (10 Gbps) on USB 3.1 Gen 2 (Optional), SuperSpeed (5 Gbps) on USB 3.0, High Speed (480 Mbps) and Full Speed (12 Mbps) modes on USB 2.0. The USB interface is used for AT command communication, data transmission, GNSS NMEA output, software debugging, firmware upgrade and so on.

- PCIe interface:

5G S-Module includes a PCIe interface, which is compliant with PCI Express Specification Revision 3.0.

- UART interface:

The module provides 3 UART interfaces: the main UART interface, the debug UART interface, and the BT UART interface.

- PCM and I^2C interface:

5G S-Module supports audio communication via PCM digital interface and I^2C interface. We recommend to support at least one interface in the future revision of this whitepaper.

- SPI interface

5G S-Module supports short-distance communication via SPI interface.

- SGMII/RGMII interface

The module shall support at least one interface, RMGII interface or SGMII interface. SGMII/RGMII interface is used to connect to Ethernet. Parallel with Gigabit media independent interface

- SDIO interface

5G S-Module supports SDIO interface, the SDIO interface supports three signal transmission modes, include SPI, 1-bit and 4-bit. The module shall support 4-bit.

- MIPI interface

MIPI interface includes: MIPI_CSI and MIPI_DSI. The smart type of 5G S-Module shall support both MIPI_CSI and MIPI_DSI

5.2.2.6 AP/MCU

The 5G S-Module may be a series of modules, depending on different computing capabilities.

1) Applications such as artificial intelligence demand that S-Module should provide high performance computing capability. Hence, the 5G S-Module used in these fields should

include a processor running at 1.3 GHz or higher, more than 1 GB of RAM and 4 GB of ROM.

2) Applications such as router and gateway do not require that S-Module provide high performance computing capability. Hence, the 5G S-Module used in these fields should include a processor running at 800 MHz or higher, more than 512 Mbyte of RAM and 512 MByteGB of ROM.

5.2.2.7 Antenna

The plug and play devices such as USB Dongle Wireless Modem Stick demand built-in antennas, which should be included in the 5G S-Modules.

6 The Industry Status

This section studies the global cellular module industry status, market share, growth opportunity, key players and challenges.

6.1 The Industry Status of 4G Module

According to GSMA estimates, the number of cellular M2M connections in the world will reach 1 billion in 2020, with an average annual growth rate of 26.8%.

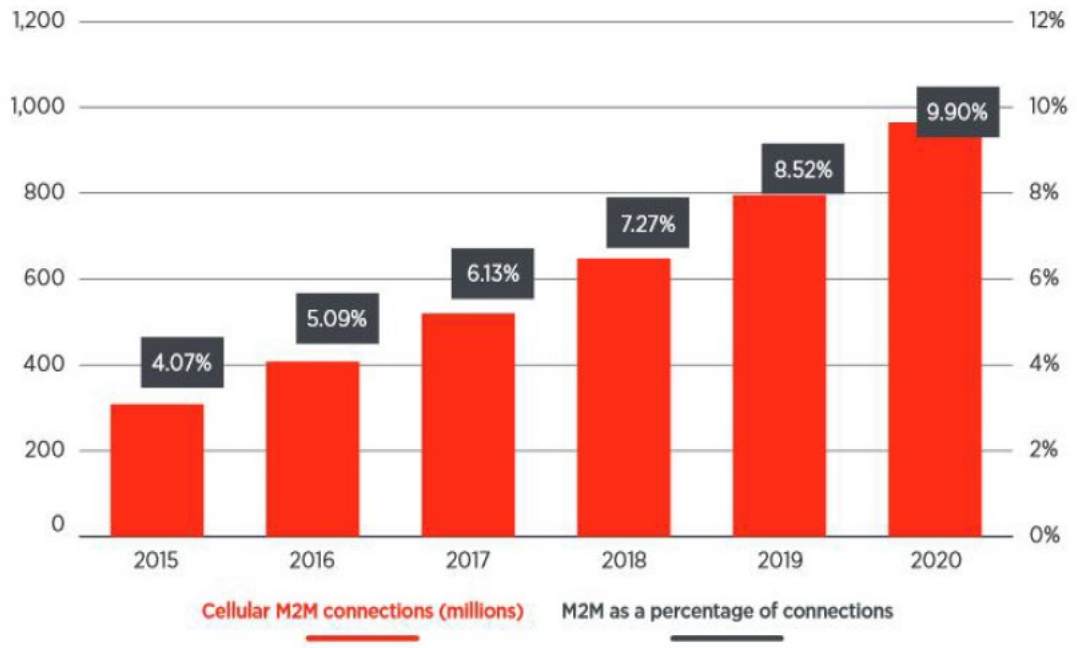


Figure 6-1 Forecast of global cellular M2M connections (From GSMA)

Cellular IoT modules are devices that allow for M2M connectivity across a variety of communication networks. The module is widely used in wireless POS, automobile, smart metering, connect laptop, CCTV, vehicle monitoring, remote control, telemetry, gateway, digital signage, vending machine, robot control, smart agriculture etc.

Industry application of cellular module is closely related to the construction of carriers' network. The commonly communication technologies are 2G,3G and 4G, some carries are also being deployed Cat.NB1 and Cat.M1 technologies. At the end of 2017, 644 public LTE networks have been deployed and have covered 200 countries/areas. With the evolution of carrier's network, more and more applications are switch to LTE modules from GSM/WCDMA modules.

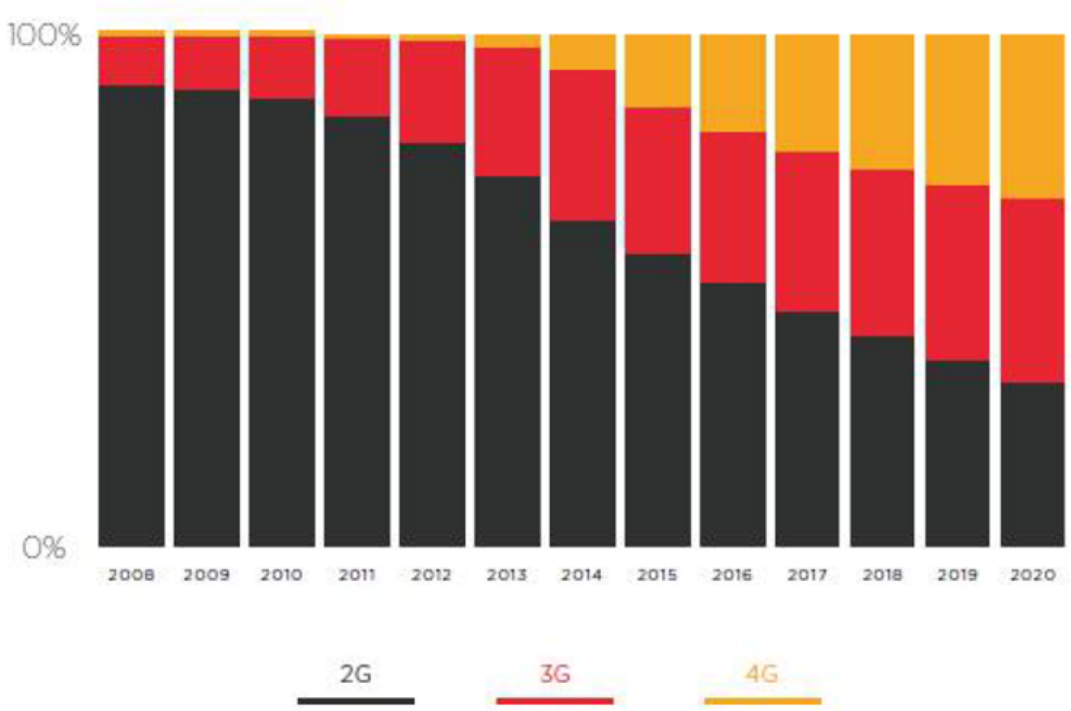


Figure 6-2 Forecast of 2G/3G/4G M2M connections (From Ericsson)

The major module suppliers include Simcom, Fibocom, Quectel, Telit, Sierra wireless, Gemalto, U-Blox, ZTE Welink, Neoway etc.

Multiple application brings a fragmented LTE category application. Some use LTE Cat1 or Cat3 for replacing 3G technology because of carrier network upgrade, some use LTE Cat4 for better network coverage in these five years like china national grid, some use LTE Cat6 or Cat9 for better downlink data throughput, and some use Cat16 or above for both downlink and uplink, also for pre-5G research.

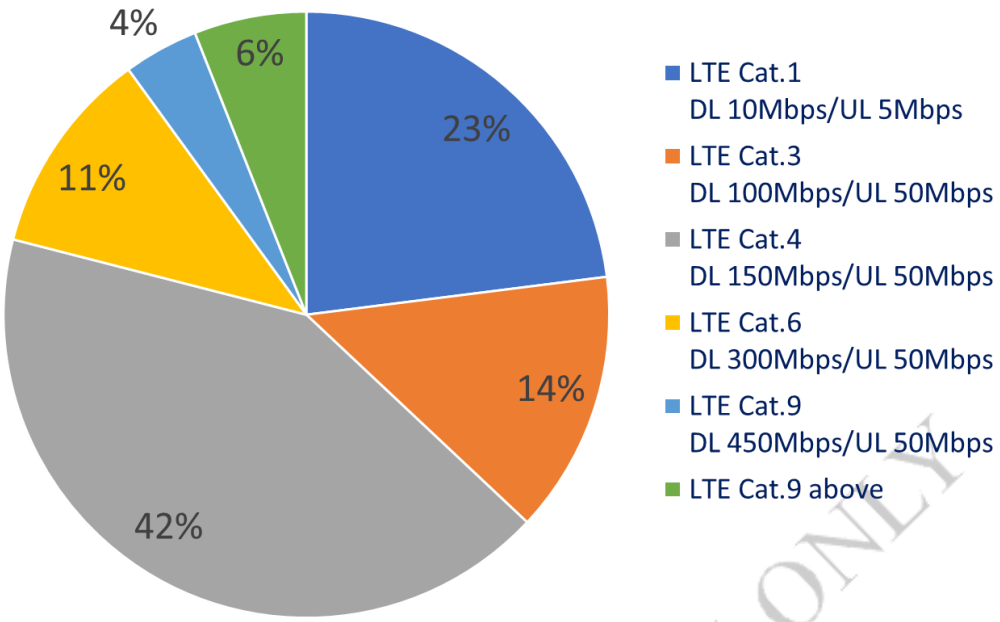


Figure 6-3 Percentage of different LTE category (From CMCC)

That also brings different kinds of module dimension in the market. There are standard interfaces like mini-PCIe and M.2, and other private definition interfaces. There are the different form factors like LCC, LGA, LCC+LGA. Even the same form factor module has different dimension and different pin definition between different module vendors.

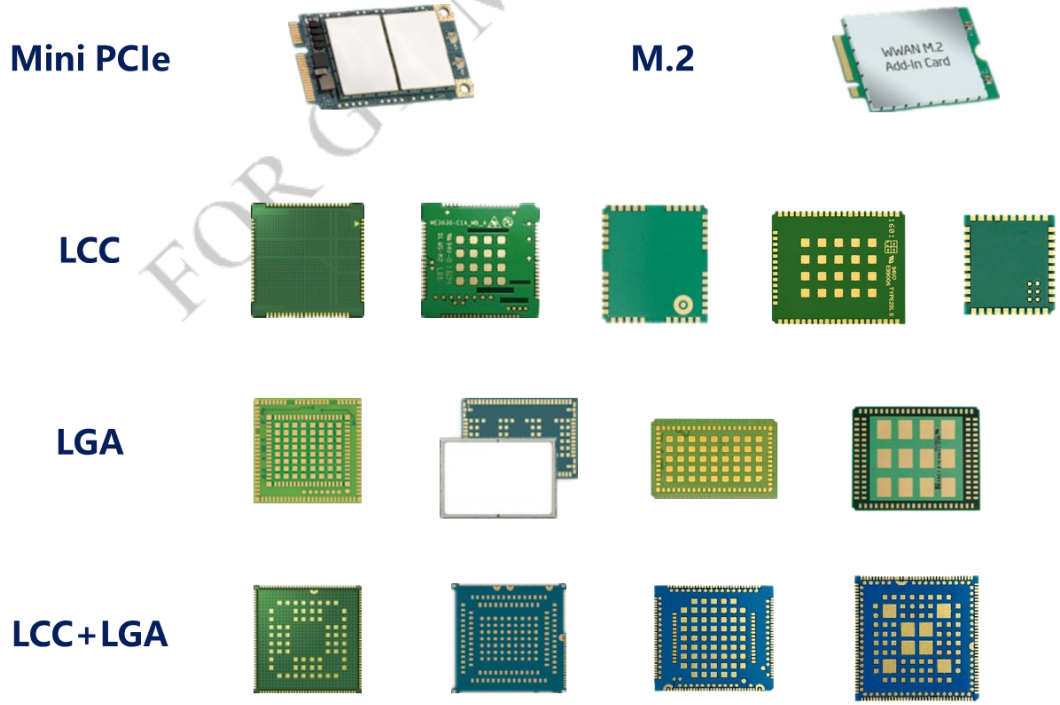


Figure 6-4 Different form factor of LTE module (From public data)

6.2 How to make 5G S-Module?

The upstream of the cellular module is vendors of the standardized baseband chip, and the downstream is the application of industry.

The requirement of 5G S-Module will focus on the eMBB application.

The R&D of cellular module need to have strong communication technology, signal processing technology, information processing technology and other professional development capabilities, and need to have a strong protocol knowledge, OS drivers, embedded software development capabilities.

6.3 The Industry Status of 5G Chipset

Due to the prospect of 5G, the main manufacturers are constantly pushing forward the development process of chip products. According to the GSA report and news released by the companies, the announced 5G chipsets are summarized as follows:

- Hi-Silicon (Huawei): the first generation 5G-only Balong 5G01 cellular modem, the second generation LTE/5G Balong 5000 cellular modem, and the 5G version processor Kirin 990.
- Intel: the XMM8060 and XMM8160 cellular modems. [Note: Intel has confirmed its withdrawal from the 5G mobile modem market. Its previously announced XMM8060 and XMM8160 cellular modems will not be produced.] Mediatek: the Helio M70 modem and the multi-mode 5G SoC with Helio M70 modem built-in.
- Qualcomm: the Snapdragon 855 mobile platform, the Snapdragon X50 and X55 modems, and the 8cx 5G platform for laptops.
- Samsung: the Exynos 5100 (S5T5100) modem and the first 5G-integrated mobile processor Exynos 980.
- UNISOC: the 5G technology platform MAKALU and its first 5G Modem IVY510.
- U-Blox: the 5G-upgradeable IoT chipset UBX-R5, which will in the future be (but is not currently) capable of supporting 5G with an OTA software upgrade.

Regarding the performance of above listed 5G chipsets, the peak downlink speeds for the commercial modems range from 4.7 Gbps to 6.5 Gbps (Qualcomm's Snapdragon X55 is expected to have a peak theoretical throughput of 7 Gbps). The maximum peak theoretical uplink speeds range from 1.5 Gbps to 3.5 Gbps (from available data). In addition, at least half the commercially available 5G-capable chipsets can support LTE as well as 5G services.

6.4 The Industry Status of 5G Module

The mainstreaming module vendors have started developing 5G modules based on available 5G chipsets. According to the GSA report released in September 2019,

- **28** 5G modules have been announced by **11** vendors.
- **19** 5G modules are developed based on Qualcomm Snapdragon X55 modem, **one** 5G module based on Huawei Balong 5000 modem, **one** to be confirmed, and **7** with no data.
- **17** 5G modules support Sub-6GHz only, **7** 5G modules support both Sub-6GHz and mmWave, and **4** with no data.
- **3** 5G modules are designed for IoV, i.e. Internet of Vehicle.

Most of the announced 5G modules areconsidered to be at a pre-commercial stage. Some modules are available for sampling and commercially available in 2020.

6.5 The Industry Status of 5G Device

Since the beginning of 2019, the number of 5G devices has grown quickly. According to the GSA report, by 10 September 2019,

- **56** vendors have announced available or forthcoming 5G devices, including sub-brands separately.
- **129** 5G devices in **15** form factors have been announced, including **41** phones, **28** indoor/outdoor CPE devices, **28** modules, **9** hotspots, **4** routers, **3** robots, **3** televisions, **2** USB terminals/dongles, **2** snap-on dongles/adapters, **2** IoT routers, **2** drones, **2** head-mounted displays, **one** laptop, **one** switch, and **one** vending machine.
- **Some of** the announced **5G** devices have been commercially available, while more devices are in the phase of pre-commercial, sampling, or availability unknown.

7 The Basic functions Requirements on 5G S-Module

7.1 Management Functions

7.1.1 Identity Management

5G S-Module should have module identity. The module identity uses shall be subject to IMEI , to ensure that the management platform associates the module identification with the IMSI of user card.

7.1.2 Status Management

5G S-Module should have capability of status management. .The module status information includes: hardware status, software status and communication status.

7.1.3 Parameter Preset Management

5G S-Module should be preset for cellular network bearer access parameters, including but not limited to APN, SMS center number, IP(or URL) and port number. If the preset parameters are inconsistent with the parameters delivered by the network, the parameters will be updated using parameters delivered by the network

7.2 SIM Functions

5G S-Module should support one or more of pluggable SIM/USIM/CSIM interface, SMD type SIM/USIM/CSIM（eUICC）and other SIM form, may support writing card using OTA mode. Debug Functions

7.3 Debug Functions

The 5G S-Module needs to support developing debug log, opening and closing debug log and outputting debug log via UART or USB or SPI interface.

7.4 Firmware Upgrade Functions

The 5G S-Module should support secured firmware upgrade. The firmware of 5G S-Module could be upgraded by FOTA. The implementation of firmware upgrade depends on device implementation.

The update workflow includes FOTA initializing, downloading update package segment, getting FOTA update result, getting package name, getting package version and firmware upgrading.

8 The Hardware Technical Requirements on 5G S-Module

Basing on variety of characteristics, form factor, sizes, etc, the 5G S-Module could be classified into 3 types shown below: Basic Type, Smart Type and All-in-one Type.

Type	**Basic Type**	**Smart Type**	**All-in-one Type**
Characteristics	Only communication capability	High performance Application Processor	Built-in antennas
Form Factor	LGA and M.2	LCC+LGA	Dongle
Size	LGA: ≤ 52mm*52mm*3.55mm M.2: ≤ 30mm*52mm*2.3mm ≤ 30mm*52mm*3.6mm	≤ 44mm*45mm*3.55mm	SMA: ≤ 52mm*93mm SLA: ≤ 44mm*70mm

8.1 5G S-Module Basic Type-L

8.1.1 Diagram

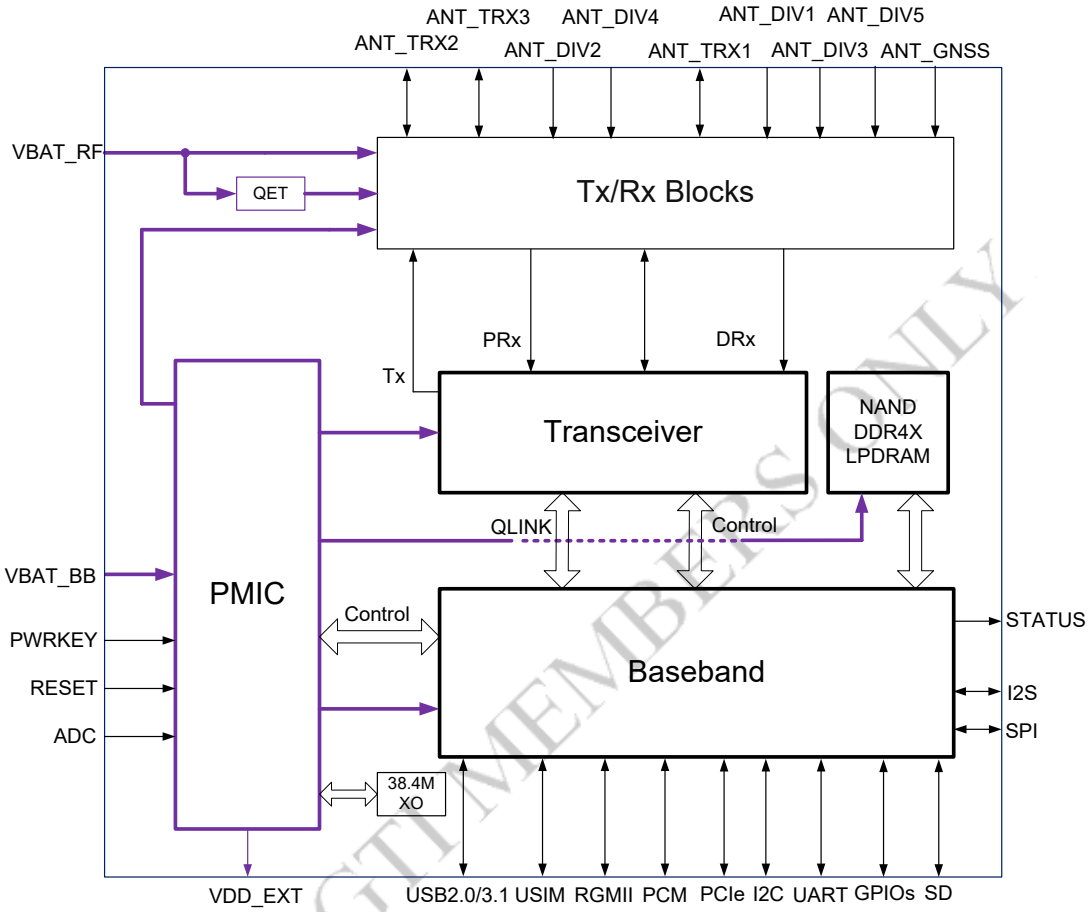


Figure 8-1 5G S-Module Basic Type-L Diagram

8.1.2 Pin Layout

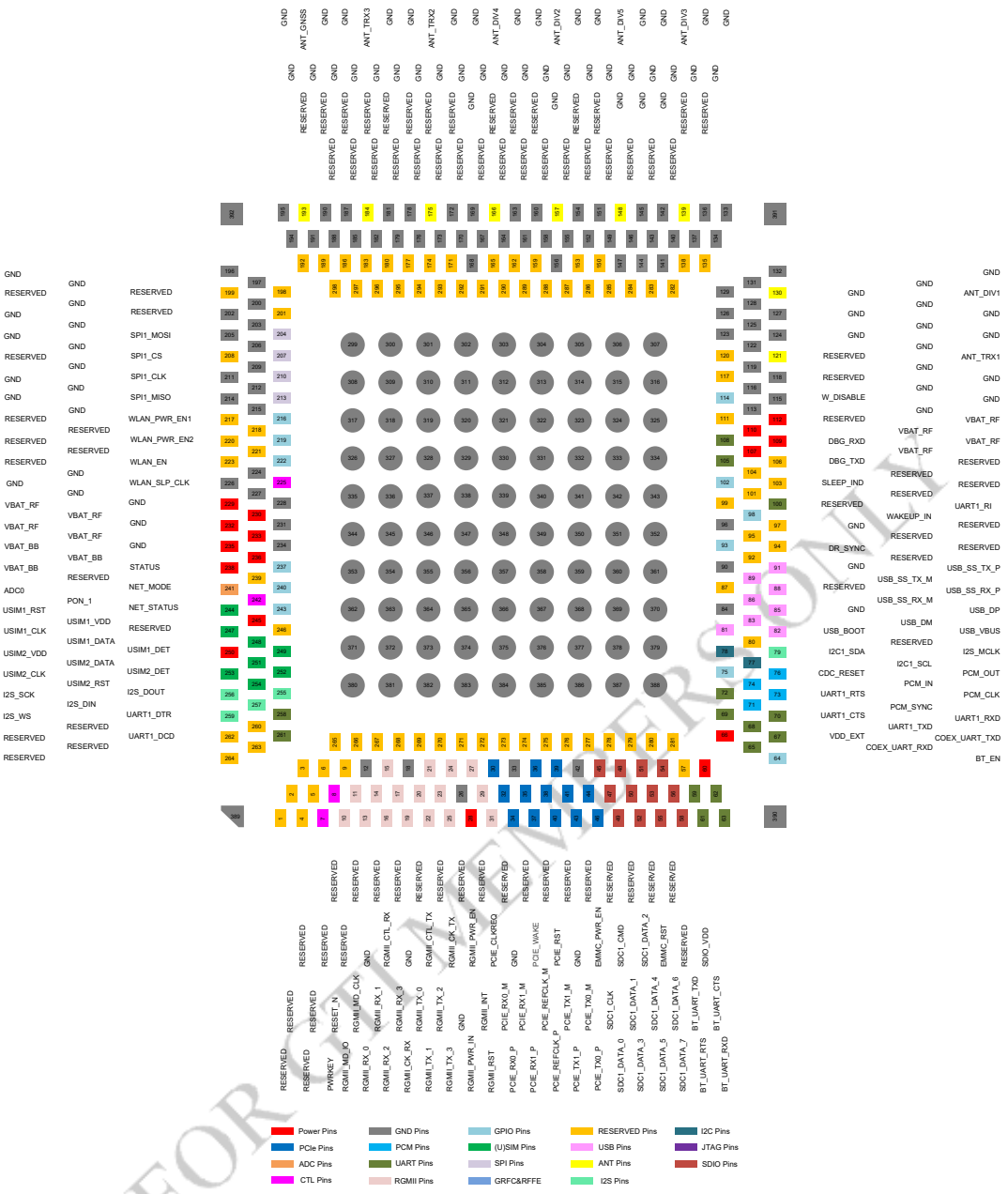


Figure 8-2 5G S-Module Basic Type-L Pin Layout-1

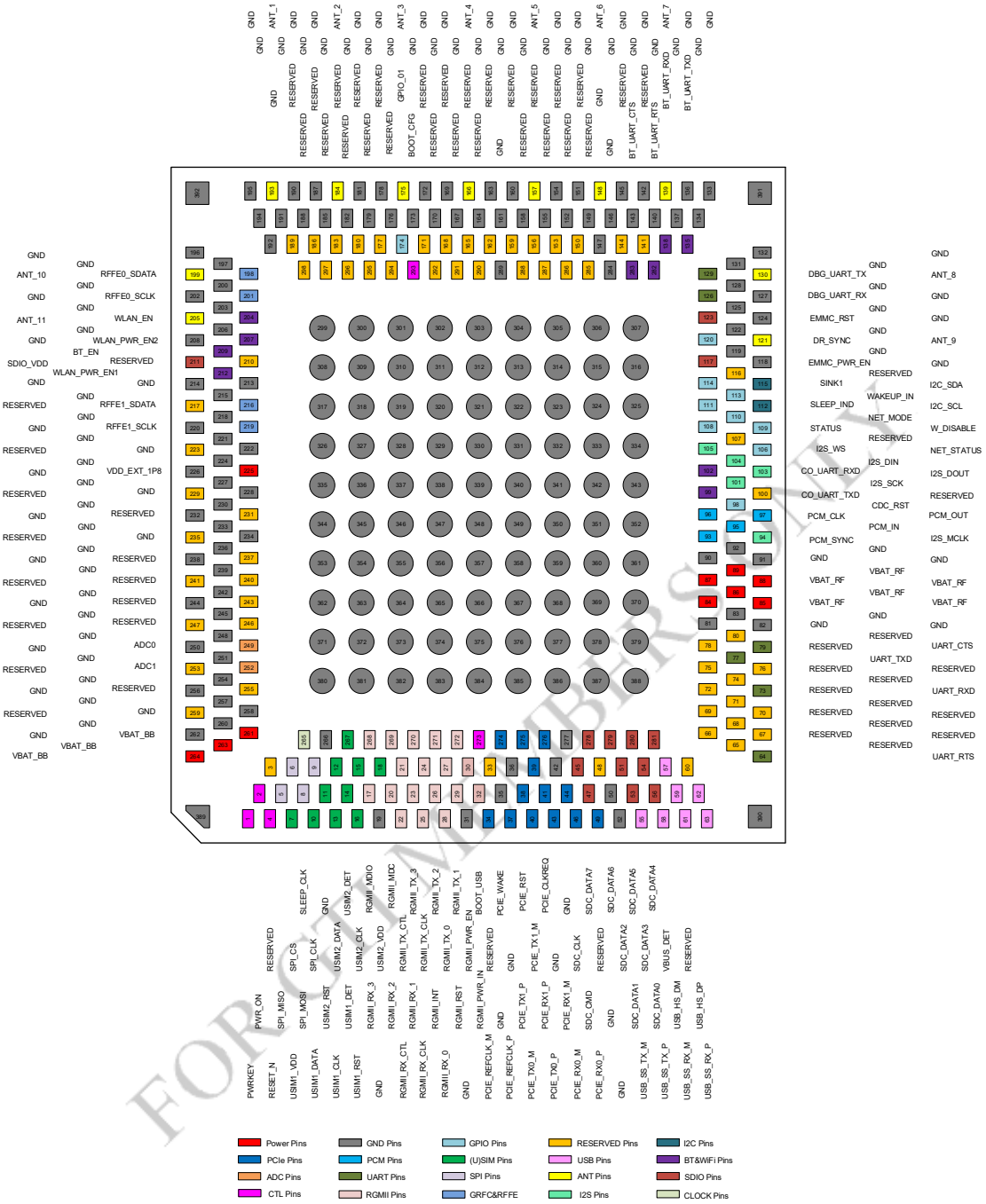


Figure 8-2A 5G S-Module Basic Type-L Pin Layout-2

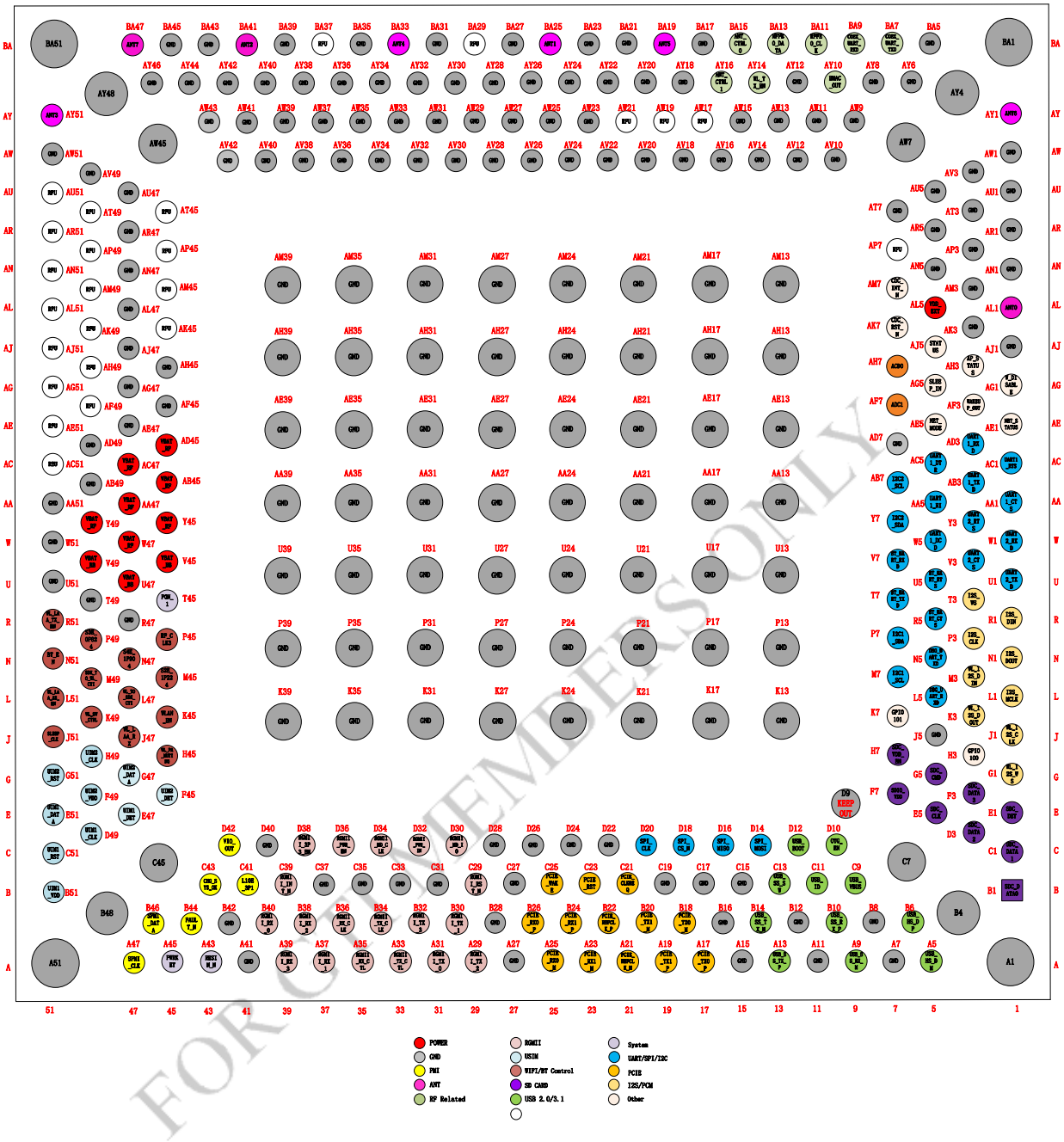
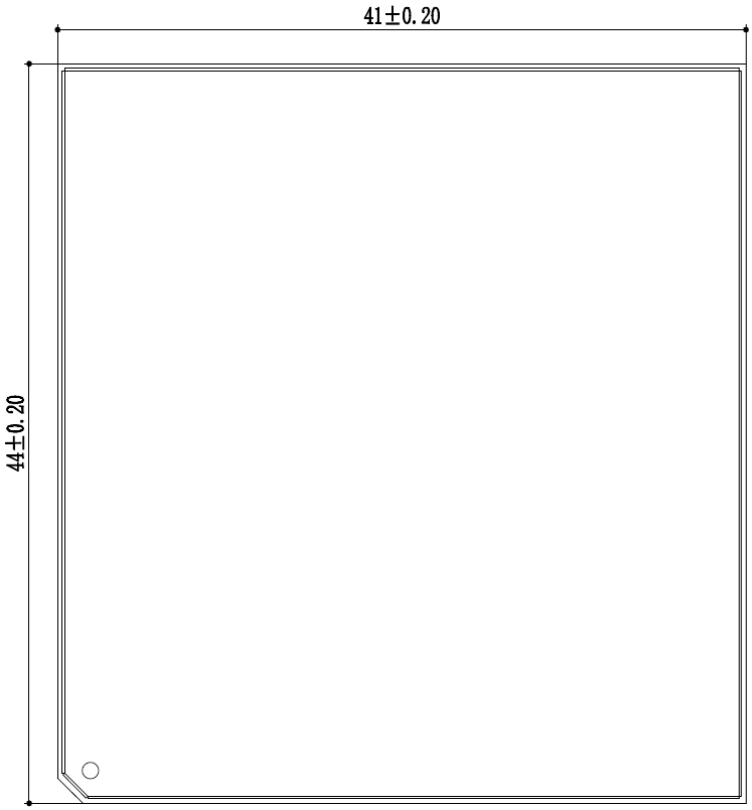
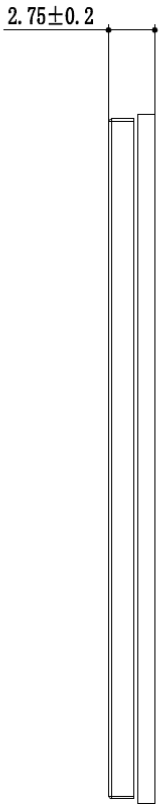


Figure 8-2B 5G S-Module Basic Type-L Pin Layout-3

8.1.3 Pin Size



Top View



Side View

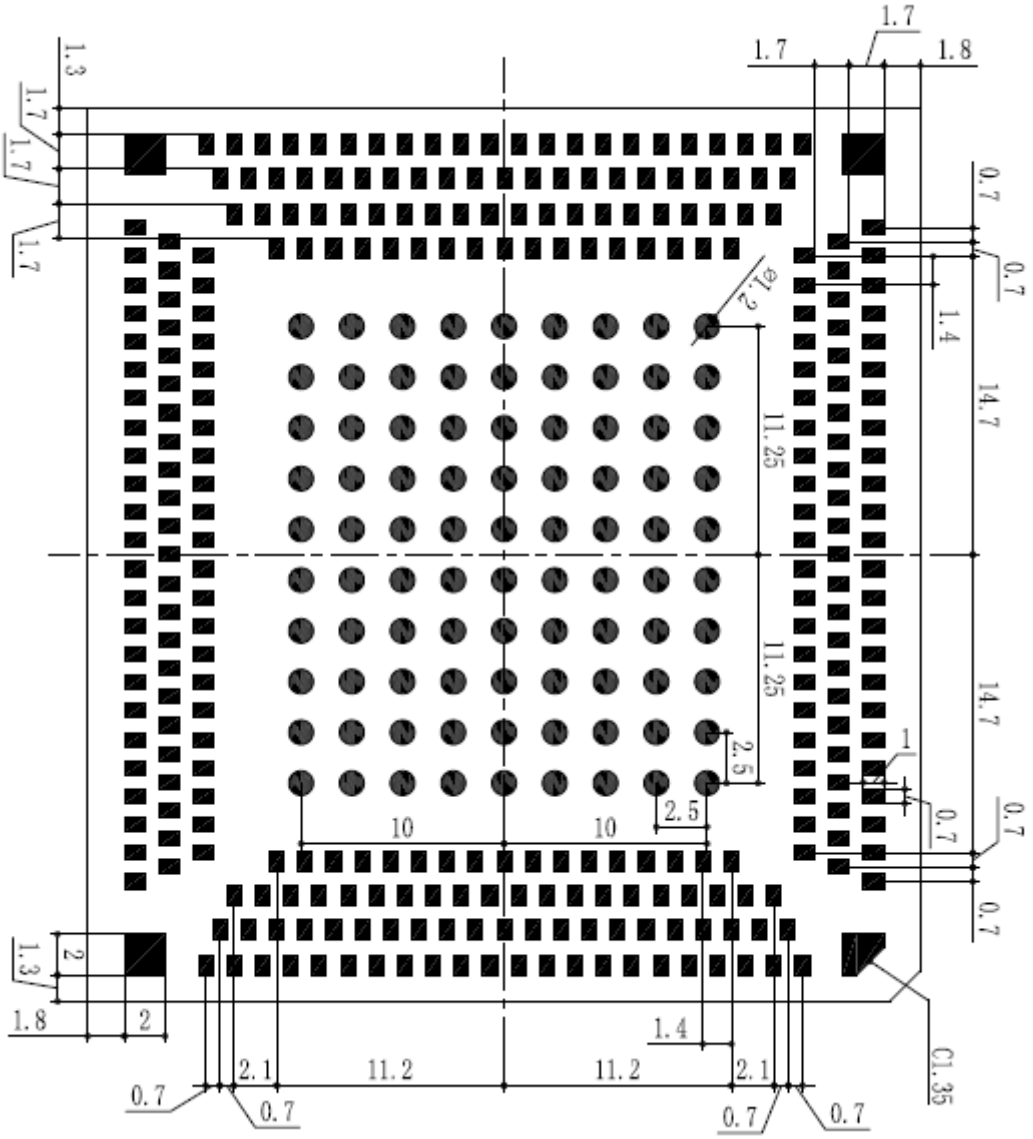


Figure 8-3 5G S-Module Basic Type-L Pin Size (Layout-1 and Layout-2)

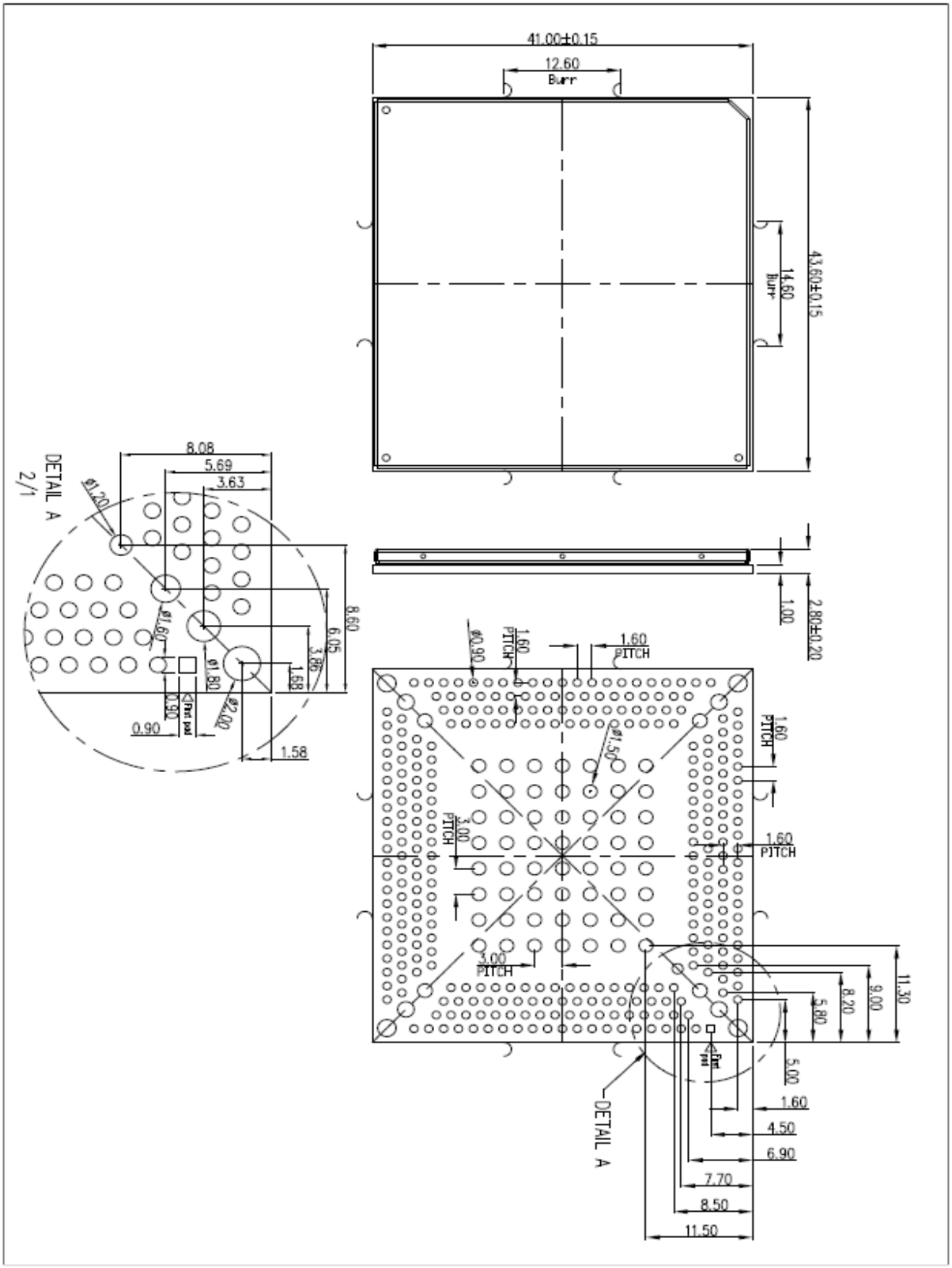


Figure 8-3A 5G S-Module Basic Type-L Pin Size (Layout-3)

8.1.4 Pin Definition

Table 8-1 5G S-Module Basic Type-L Pin Definition(Layout-1)

Pin name	Pin No.	Default status	Description	Comment
Power supply				
VBAT_BB	235,236,238	PI	Baseband power supply.	Can connect these pins together to the same power source.
VBAT_RF	107,109，110,112，,229,230,232,233	PI	RF power supply.	
VDD_EXT	66	PO	1.8 output with Max 50mA current output for external circuit, such as level shift circuit.	If unused, please keep it open.
System Control				
PWRKEY	7	DI	System power on/off control input, active low.	
PON_1	242	DI	Pull it to high level will make the module turn on automatically.	
RESET	8	DI	System reset control input, active low.	
Status Indicator				
STATUS	237	DO	System status output	
NET_MODE	240	DO	Network Mode output	
NET_STATUS	243	DO	Network status output	
USB interface				
USB_VBUS	82	AI	USB detection input.	If unused, please keep them open.
USB_DP	85	AIO	Positive line of the differential, bi-directional USB signal.	
USB_DM	83	AIO	Negative line of the differential, bi-directional USB signal.	
USB_BOOT	81	DI	Force the module to boot from USB port	

USB_SS_ TX_P	91	AO	USB Super-Speed transmit – plus	
USB_SS_ TX_M	89	AO	USB Super-Speed transmit – minus	
USB_SS_ RX_P	88	AI	USB Super-Speed receive – plus	
USB_SS_ RX_M	86	AI	USB Super-Speed receive – minus	
(U)SIM interface				
USIM1_VDD	245	PO	Power supply for (U)SIM card1	1.8V or 2.85V power domain
USIM1_DATA	248	DIO	Data signal of (U)SIM card1	
USIM1_CLK	247	DO	USIM1 clock output	
USIM1_RST	244	DO	USIM1 Reset output	
USIM1_DET	249	DI	USIM1 card detecting input. H: USIM is removed L: USIM is inserted	1.8V power domain. If unused, keep it open.
USIM2_VDD	250	PO	Power supply for (U)SIM card2	1.8V or 2.85V power domain
USIM2_DATA	251	DIO	Data signal of (U)SIM card2	
USIM2_CLK	253	DO	Clock signal of (U)SIM card2	

USIM2_RST	254	DO	Reset signal of (U)SIM card2	
USIM2_DET	252	DI	USIM2 card detecting input. H: USIM is removed L: USIM is inserted	1.8V power domain. If unused, keep it open.
SPI interface				
SPI1_CS	207	DO	SPI chip select	
SPI1_CLK	210	DO	SPI clock	
SPI1_MOSI	204	DO	Master output slaver input	
SPI1_MISO	213	DI	Master input slaver output	
UART1 interface				
UART1_RI	100	DO	Ring Indicator	If unused, please keep them open.
UART1_DCD	261	DO	Data carrier detectsion	
UART1_CTS	69	DO	Clear to Send	
UART1_RTS	72	DI	Request to send	
UART1_DTR	258	DI	Data Terminal Ready,sleep mode control	
UART1_TXD	68	DO	Transmit Data	
UART1_RXD	70	DI	Receive Data	
Debug interface				
DBG_RXD	108	DI	Debug UART receive Data	If unused, please keep them open.
DBG_TXD	105	DO	Debug UART transmit Data	
BT UART interface				

BT_UART_TXD	59	DO	BT UART Transmit Data	If unused, please keep them open.
BT_UART_RXD	63	DI	BT UART Receive Data	
BT_UART_RTS	61	DI	BT UART Request to send	
BT_UART_CTS	62	DO	BT UART Clear to Send	
ADC interface				
ADC0	241	AI	ADC input	If unused, please keep them open.
PCM interface				
PCM_IN	74	DI	PCM data input	If unused, please keep them open.
PCM_OUT	76	DO	PCM data output	
PCM_SYNC	71	DIO	PCM synchronous signal	
PCM_CLK	73	DIO	PCM clock output	
I2S interface				
I2S_WS	259	DIO	I2S word select	1.8V power domain
I2S_SCK	256	DIO	I2S bit clock	
I2S_DIN	257	DI	I2S data input	
I2S_DOUT	255	DO	I2S data output	
I2C interface				
I2C1_SCL	77	OD	I2C clock output	OD gate driver, pull-up resistors of 2.2KR to the VDD_1V8 are needed. If unused, please keep open
I2C1_SDA	78	OD	I2C data input/output	
PCIE interface				
PCIE_REFCLK_P	40	AO	PCIe reference clock plus	If unused, please keep them open.

PCIE_REFCLK_M	38	AO	PCIe reference clock minus	
PCIE_TX0_M	44	AO	PCIe Lane 0 transmit minus	
PCIE_TX0_P	46	AO	PCIe Lane 0 transmit plus	
PCIE_RX0_M	32	AI	PCIe Lane 0 receive minus	
PCIE_RX0_P	34	AI	PCIe Lane 0 receive plus	
PCIE_TX1_M	41	AO	PCIe Lane 1 transmit minus	
PCIE_TX1_P	43	AO	PCIe Lane 1 transmit plus	
PCIE_RX1_M	35	AI	PCIe Lane 1 receive minus	
PCIE_RX1_P	37	AI	PCIe Lane 1 receive plus	
PCIE_CLKREQ	30	DIO	PCIe clock request	
PCIE_RST	39	DIO	PCIe reset	
PCIE_WAKE	36	DIO	PCIe wake-up host	
WLAN interface				
WLAN_PWR_ EN1	216	DO	WLAN power enable1	If unused, please keep them open.
WLAN_PWR_ EN2	219	DO	WLAN power enable2	
WAKE_SLP_CLK	225	DO	WLAN sleep clock	
WLAN_EN	222	DO	WLAN function enable	
COEX_UART_ RXD	65	DI	Coex UART Receive data	
COEX_UART_ TXD	67	DO	Coex UART Transmit data	
SD interface				

SDIO_VDD	60	PI	Power supply of SDIO data signal	1.8V or 2.85V power domain
SDC1_DATA0	49	DIO	SDIO data 0	
SDC1_DATA1	50	DIO	SDIO data 1	
SDC1_DATA2	51	DIO	SDIO data 2	
SDC1_DATA3	52	DIO	SDIO data 3	
SDC1_CMD	48	DO	SDIO command output	
SDC1_CLK	47	DO	SDIO clock output	
SDC1_DATA4	53	DIO	SDIO data 4	
SDC1_DATA5	55	DIO	SDIO data 5	
SDC1_DATA6	56	DIO	SDIO data 6	
SDC1_DATA7	58	DIO	SDIO data 7	
EMMC_RST	54	DO	Reset signal for eMMC flash	
EMMC_PWR_EN	45	DO	Enable eMMC power supply	
RGMII interface				
RGMII_MD_IO	10	DIO	RGMII MDIO management data	
RGMII_MD_CLK	11	DO	RGMII MDC management clock	
RGMII_RX_0	13	DI	RGMII receive data bit 0	

RGMII_RX_1	14	DI	RGMII receive data bit 1	
RGMII_CTL_RX	15	DI	RGMII receive control	
RGMII_RX_2	16	DI	RGMII receive data bit 2	
RGMII_RX_3	17	DI	RGMII receive data bit 3	
RGMII_CK_RX	19	DI	RGMII receive clock	
RGMII_TX_0	20	DO	RGMII transmit data bit 0	
RGMII_CTL_TX	21	DO	RGMII transmit control	
RGMII_TX_1	22	DO	RGMII transmit data bit 1	
RGMII_TX_2	23	DO	RGMII transmit data bit 2	
RGMII_CK_TX	24	DO	RGMII transmit clock	
RGMII_TX_3	25	DO	RGMII transmit data bit 3	
RGMII_PWR_EN	27	DO	Used to enable external LDO to supply 2.5V power to RGMII_PWR_IN	1.8V power domain
RGMII_PWR_IN	28	PI	Power input for internal RGMII circuit	
RGMII_INT	29	DI	RGMII PHY interrupt output	1.8V power domain
RGMII_RST	31	DO	Reset output for RGMII PHY	
RF interface				
ANT_TRX2	175	AI/AO	Main antenna2, support TX and RX	

ANT_TRX3	184	AI/AO	Main antenna3, support TX and RX	
ANT_DIV2	157	AI	Diversity receive antenna 2	
ANT_DIV4	166	AI	Diversity receive antenna 4	
ANT_TRX1	121	AI/AO	Main antenna1, support TX and RX	
ANT_DIV1	130	AI	Diversity receive antenna 1	
ANT_DIV3	139	AI	Diversity receive antenna 3	
ANT_DIV5	148	AI	Diversity receive antenna 5	
ANT_GNSS	193	AI	GNSS antenna interface	
GPIO				
WAKEUP_IN	98	DI	Sleep Mode control	
W_DISABLE	114	DI	Flight Mode control	
SLEEP_IND	102	DO	Indicating module sleep status	
Others				
BT_EN				
CDC_RESET	75	DO	Reset of codec	
I2S_MCLK	79	DO	Clock output	
DR_SYNC	93	DO	Navigation 1PPS time sync output	
GND				
GND				
RESERVED				

RESERVED

Table 8-1A 5G S-Module Basic Type-L Pin Definition(Layout-2)

Pin name	Pin No.	Default status	Description	Comment
Power supply				
VBAT_BB	264,263,261	PI	Baseband power supply.	Can connect these pins together to the same power source.
VBAT_RF	88,85,89,86,87,84	PI	RF power supply.	
VDD_EXT_1V8	225	PO	1.8 output with Max 50mA current output for external circuit, such as level shift circuit.	If unused, please keep it open.
System Control				
PWRKEY	1	DI	System power on/off control input, active low.	
PWR_ON	2	DI	Pull it to high level will make the module turn on automatically.	
BOOT_CFG	293	DI	Module boot config	
BOOT_USB	273	DI	Force the module to boot from USB port	
RESET_N	4	DI	System reset control input, active low.	
USB interface				
VBUS_DET	57	AI	USB detection input.	If unused, please keep them open.
USB_HS_DP	62	AIO	Positive line of the differential, bi-directional USB signal.	
USB_HS_DM	59	AIO	Negative line of the differential, bi-directional USB signal.	
USB_SS_ TX_P	58	AO	USB Super-Speed transmit – plus	
USB_SS_ TX_M	55	AO	USB Super-Speed transmit – minus	
USB_SS_ RX_P	63	AI	USB Super-Speed receive – plus	

USB_SS_ RX_M	61	AI	USB Super-Speed receive – minus	
SIM interface				
USIM1_VDD	7	PO	Power supply for (U)SIM card1	1.8V or 2.85V power domain
USIM1_DATA	10	DIO	Data signal of (U)SIM card1	
USIM1_CLK	13	DO	Clock signal of (U)SIM card1	
USIM1_RST	16	DO	Reset signal of (U)SIM card2	
USIM1_DET	14	DI	USIM1 card detecting input.	1.8V power domain. If unused, keep it open.
USIM2_VDD	18	PO	Power supply for SIM card2	1.8V or 2.85V power domain
USIM2_DATA	12	DIO	Data signal of SIM card2	
USIM2_CLK	15	DO	Clock signal of SIM card2	
USIM2_RST	11	DO	Reset signal of SIM card2	
USIM2_DET	267	DI	USIM2 card detecting input.	1.8V power domain. If unused, keep it open.
SPI interface				

SPI_CS	6	DO	SPI chip select	
SPI_CLK	9	DO	SPI clock	
SPI_MOSI	8	DO	Master output slaver input	
SPI_MISO	5	DI	Master input slaver output	
UART interface				
UART_CTS	79	DO	Clear to Send	
UART_RTS	64	DI	Request to send	
UART_TXD	77	DO	Transmit Data	
UART_RXD	73	DI	Receive Data	
Debug interface				
DBG_UART_RX	126	DI	Debug UART receive Data	If unused, please keep them open.
DBG_UART_TX	129	DO	Debug UART transmit Data	
BT UART interface				
BT_UART_TXD	135	DO	BT UART Transmit Data	If unused, please keep them open.
BT_UART_RXD	138	DI	BT UART Receive Data	
BT_UART_RTS	282	DI	BT UART Request to send	
BT_UART_CTS	283	DO	BT UART Clear to Send	
ADC interface				
ADC0	249	AI	Analog-digital converter input	If unused, please keep them open.
ADC1	252	AI	Analog-digital converter input	

PCM interface				
PCM_IN	95	DI	PCM data input	If unused, please keep them open.
PCM_OUT	97	DO	PCM data output	
PCM_SYNC	93	DO	PCM synchronous signal	
PCM_CLK	96	DO	PCM clock output	
I2S interface				
I2S_WS	105	DO	I2S word select	1.8V power domain
I2S_SCK	101	DO	I2S bit clock	
I2S_DIN	104	DI	I2S data input	
I2S_DOUT	103	DO	I2S data output	
I2S_MCLK	94	DO	Clock output	
I2C interface				
I2C_SCL	112	DO	I2C clock output	OD gate driver, pull-up resistors of 2.2KR to the VDD_EXT_1P8 are needed. If unused, please keep open
I2C_SDA	115	DIO	I2C data input/output	
PCIE interface				
PCIE_REFCLK_P	37	AO	PCIe reference clock plus	If unused, please keep them open.
PCIE_REFCLK_M	34	AO	PCIe reference clock minus	
PCIE_TX0_M	40	AO	PCIe Lane 0 transmit minus	
PCIE_TX0_P	43	AO	PCIe Lane 0 transmit plus	

PCIE_RX0_M	46	AI	PCIe Lane 0 receive minus	
PCIE_RX0_P	49	AI	PCIe Lane 0 receive plus	
PCIE_TX1_M	39	AO	PCIe Lane 1 transmit minus	
PCIE_TX1_P	38	AO	PCIe Lane 1 transmit plus	
PCIE_RX1_M	44	AI	PCIe Lane 1 receive minus	
PCIE_RX1_P	41	AI	PCIe Lane 1 receive plus	
PCIE_CLKREQ	276	DIO	PCIe clock request	
PCIE_RST	275	DIO	PCIe reset	
PCIE_WAKE	274	DIO	PCIe wake	
WLAN interface				
WLAN_PWR_EN1	212	DO	WLAN power enable1	If unused, please keep them open.
WLAN_PWR_EN2	207	DO	WLAN power enable2	
SLEEP_CLK	265	DO	WLAN sleep clock	
WLAN_EN	204	DO	WLAN function enable	
CO_UART_ RXD	102	DI	Coex UART Receive data	
CO_UART_ TXD	99	DO	Coex UART Transmit data	
SD interface				
SDIO_VDD	211	PI	Power supply of SDIO data signal	1.8V or 2.85V power domain
SDC_DATA0	56	DIO	SDIO data 0	
SDC_DATA1	53	DIO	SDIO data 1	
SDC_DATA2	51	DIO	SDIO data 2	

SDC_DATA3	54	DIO	SDIO data 3	
SDC_CMD	47	DO	SDIO command output	
SDC_CLK	45	DO	SDIO clock output	
SDC_DATA4	281	DIO	SDIO data 4	
SDC_DATA5	280	DIO	SDIO data 5	
SDC_DATA6	279	DIO	SDIO data 6	
SDC_DATA7	278	DIO	SDIO data 7	
EMMC_RST	123	DO	Reset signal for eMMC flash	
EMMC_PWR_EN	117	DO	Enable eMMC power supply	
RGMII interface				
RGMII_MDIO	268	DIO	RGMII MDIO management data	
RGMII_MDC	269	DO	RGMII MDC management clock	
RGMII_RX_0	28	DI	RGMII receive data bit 0	
RGMII_RX_1	23	DI	RGMII receive data bit 1	
RGMII_RX_CTL	22	DI	RGMII receive control	
RGMII_RX_2	20	DI	RGMII receive data bit 2	
RGMII_RX_3	17	DI	RGMII receive data bit 3	

RGMII_RX_CLK	25	DI	RGMII receive clock	
RGMII_TX_0	27	DO	RGMII transmit data bit 0	
RGMII_TX_CTL	21	DO	RGMII transmit control	
RGMII_TX_1	272	DO	RGMII transmit data bit 1	
RGMII_TX_2	271	DO	RGMII transmit data bit 2	
RGMII_TX_CLK	24	DO	RGMII transmit clock	
RGMII_TX_3	270	DO	RGMII transmit data bit 3	
RGMII_PWR_EN	30	DO	Used to enable external LDO to supply 2.5V power to RGMII_PWR_IN	1.8V power domain
RGMII_PWR_IN	32	PI	Power input for internal RGMII circuit	
RGMII_INT	26	DI	RGMII PHY interrupt output	1.8V power domain
RGMII_RST	29	DO	Reset output for RGMII PHY	
RF interface				
ANT_1	193	AIO	N77/78/79 DRX	
ANT_2	184	AIO	RESERVED	
ANT_3	175	AIO	MB MIMO PRX HB MIMO PRX N41/77/78/79 TRX	
ANT_4	166	AIO	RESERVED	

ANT_5	157	AIO	N77/78/79 MIMO DRX MB MIMO DRX HB MIMO DRX	
ANT_6	148	AIO	N77/78/79 Second TRX	
ANT_7	139	AIO	LB DRX MB DRX HB DRX(n41)	
ANT_8	130	AIO	LB TRX0 PRX MB TRX0 PRX HB TRX0 PRX N41 Second TRX	
ANT_9	121	AIO	Reserved	
ANT_10	199	AI	GNSS	
ANT_11	205	AIO	Reserved	
RFFE				
RFFE0_SDATA	198	DIO	RF front end 0 data	
RFFE0_SCLK	201	DO	RF front end 0 clock	
RFFE1_SDATA	216	DIO	RF front end 1 data	
RFFE1_SCLK	219	DO	RF front end 1 clock	
GPIO				
W_DISABLE	109	DI	Flight Mode control	
NET_STATUS	106	DO	Network status output	
NET_MODE	110	DO	Network Mode output	
SLEEP_IND	111	DO	Indicating module sleep status	
STATUS	108	DO	System status output	

SINK1	114	OD	Open-drain for LED drive	
WAKEUP_IN	113	DI	Sleep Mode control	
GPIO_01	174	DIO	Reserved GPIO	
Others				
BT_EN	209	DO	BT function enable	
CDC_RST	98	DO	Reset of codec	
DR_SYNC	120	DO	Navigation 1PPS time sync output	
GND				
GND	19,31,35,36,42,50,52,81,82,83,90,91,92,118,119,122,124,125,127,128,131,132,133,134,136,137,140,142,143,145,146,147,149,151,152,154,155,158,160,161,163,164,167,169,170,172,173,176,178,179,181,182,185,187,188,190,191,192,194,195,196,197,200,202,203,206,208,213,214,215,218,220,221,222,224,226,227,228,230,232,233,234,236,238,239,242,244,245,248,250,251,254,256,257,258,260,262,266,277,284,289,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392	
RESERVED				
RESERVED	3,33,48,60,65,66,67,68,69,70,71,72,74,75,76,78,80,100,107,116,141,144,150,153,156,159,162,165,168,171,177,180,183,186,189,210,217,223,229,231,235,237,240,241,243,246,247,253,255,259,285,286,287,288,290,291,292,294,295,296,297,298			No connect

Table 8-1B 5G S-Module Basic Type-L Pin Definition(Layout-3)

Pin Name	Pin No.	Default status	Functional Description	Comment
Power Supply				

VBAT_BB	V45,V49, U47	PI	V_{MAX}=4.3V V_{MIN} =3.3V V_{TYP} =3.8V	Baseband power supply input	User can connect these pins together to the same source.
VBAT_RF	Y49,AC47 ,AA47,W4 7,AD45,A B45,Y45	PI	V_{MAX} =4.3V V_{MIN} =3.3V V_{TYP} =3.8V	RF power supply input	
VDD_EXT	AL5	PO	V_{TYP} =1.8V	Output for the external IO pull up circuits	I_{OMAX}=50mA
S2E_1P224	M45	PO	V_{TYP} =1.2V	Output power for the WLAN	Only used for WLAN
S3E_0P824	P49	PO	V_{TYP} =0.8V	Output power for the WLAN	Only used for WLAN
S4E_1P904	N47	PO	V_{TYP} =1.88V	Output power for the WLAN	Only used for WLAN
L10E_3P1	C41	PO	V_{TYP} =3.08V	Output power for the PMI (USB PD-PHY)	Only used for PMI
VIO_OUT	D42	PO	V_{TYP} =1.8V	Output power for the PMI IO circuit	Only used for PMI
GND	A7,B8,A11,B12,C15,A15,B16,C17,C19,D22,D24,D26,C27,A27,B28,D28,C31,C33,C35,C37,D40,A41,B42,J5,AD7,AJ1,AK3,AM3,AN1,AN5,AP3,AR1,AR5,AT3,AT7,AU1,AU5,AV3,AW1, R47,T49,U51,W51,AA51,AB49,AD49,AE47,AF45,AH45,AG47,AJ47,AL47,AN47,AR47,AU47,AV49,AW51,AV10,AV12,AV14,AV16,AV18,AV20,AV22,AV24,AV26,AV28,AV30,AV32,AV34,AV36,AV38,AV40,AV42,AW9,AW11,AW13,AW15,AW23,AW25,AW27,AW29,AW31,AW33,AW35,AW37,AW39,AW41,AW43,AY6,AY8,AY12,AY18,AY20,AY22,AY24,AY26,AY28,AY30,AY32,AY34,AY36,AY38,AY40,AY42,AY44,AY46,BA5, BA17,BA21,BA23,BA27,BA31,BA35,BA39,BA43,BA45,AM13,AM17,AM21,AM24,AM27,AM31,AM35,AM39,AH13,AH17,AH21,AH24,AH27,AH31,AH35,AH39,AE13,AE17,AE21,AE24,AE27,AE31,AE35,AE39,AA13,AA17,AA21,AA24,AA27,AA31,AA35, AA39,U13,U17,U21,U24,U27,U31,U35,U39,P13,P17,P21,P24,P27,P31,P35,P39,K13,K17,K21,K24,K27,K31,K35,K39,A1,B4,C7,A51,B48,C45,BA1,AY4,AW7,BA51,AY48,AW45				Ground
System Control					
PWRKEY	A45	DI	1.8V	When transitioning from high to low can power on/off the module	Pull low for ＞2 s to power on the Module
PON_1	T45	DI	1.8V	When transitioning from low to high can power on the Module	Pull high for ＞2 s to power on the Module
RESIN_N	A43	DI	V_{IL} max=0.5V	When hold at a logic low can reset the module	
Status Indicator					
STATUS	AJ5	DO	1.8V	Module’s operation status output	
AP_STATUS	AH3	DI	1.8V	AP status input	
NET_MODE	AE5	DO	1.8V	Module’s network mode output	
NET_STATUS	AE1	DO	1.8V	Module’s network status output	
USB Interface					
USB_VBUS	C9	AI	V_{TYP} =5V	USB detection input	Not support charge
USB_HS_DP	B6	AIO		Positive line of the differential, bi-directional	Required 90Ω differential

				USB signal.	impedance
USB_HS_DM	A5	AIO		Negative line of the differential, bi-directional USB signal.	Compliant with USB 2.0 standard specifications
USB_SS_ TX_P	A13	AO		USB Super-Speed transmit – plus	Required 90 Ω differential Impedance Compliant with USB 3.1 standard specifications
USB_SS_TX_M	B14	AO		USB Super-Speed transmit – minus	
USB_SS_ RX_P	B10	AI		USB Super-Speed receive – plus	
USB_SS_RX_M	A9	AI		USB Super-Speed receive – minus	
USB_ID	C11	DI	1.8V	USB ID input	Need pull up by a 100K resistor to VDD_EXT out of the module
OTG_EN	D10	DO	1.8V	USB OTG power enable output	
USB_SS_SW	C13	DO	1.8V	USB Type-c switch control signal	
(U)SIM Interface					
USIM1_VDD	B51	PO	1.8/2.85V	Power output for USIM1 card, the voltage depends on the USIM1 card type	All Pins of USIM1 need add TVS at USIM1 card connector Only used for USIM function
USIM1_DATA	E51	DIO	1.8/2.85V	USIM1 Card data I/O, which has been pulled up by a 20K resistor to USIM1_VDD internally. Do not pull it up or down externally	
USIM1_CLK	D49	DO	1.8/2.85V	USIM1 clock signal	
USIM1_RST	C51	DO	1.8/2.85V	USIM1 Reset signal	
USIM1_DET	E47	DI	1.8V	USIM1 card detecting input signal which need pulled up by a 470K resistor to VDD_EXT out of the module H: USIM is removed L: USIM is inserted	
USIM2_VDD	F49	PO	1.8/2.85V	Power output for USIM2 card, the voltage depends on the USIM2 card type	All Pins of USIM2 need add TVS at USIM2 card connector Only used for USIM function
USIM2_DATA	G47	DIO	1.8/2.85V	USIM2 Card data I/O, which has been pulled up by a 20K resistor to USIM2_VDD internally. Do not pull it up or down externally	
USIM2_CLK	H49	DO	1.8/2.85V	USIM2 clock signal	
USIM2_RST	G51	DO	1.8/2.85V	USIM2 Reset signal	
USIM2_DET	F45	DI	1.8V	USIM2 card detecting input signal which need pulled up by a 470K resistor to VDD_EXT out of the module H: USIM is removed L: USIM is inserted	
SPI Interface					
SPI_CS_N	D18	DO	1.8V	SPI chip select	
SPI_CLK	D20	DO	1.8V	SPI clock	
SPI_MOSI	D14	DIO	1.8V	Master output slaver input	
SPI_MISO	D16	DIO	1.8V	Master input slaver output	
UART1 Interface					
UART1_CTS	AA1	DO	1.8V	Clear to Send	Default use for

UART1_RTS	AC1	DI	1.8V	Request to send	external device
UART1_TXD	AB3	DO	1.8V	Transmit Data	
UART1_RXD	AD3	DI	1.8V	Receive Data	
UART1_DCD	W5	DO	1.8V	Carrier detects	If not use UART function can be used as GPIO; support wakeup and interrupt function
UART1_RI	AA5	DO	1.8V	Ring Indicator	
UART1_DTR	AC5	DI	1.8V	Data Terminal Ready	
UART2 Interface					
UART2_CTS	V3	DO	1.8V	Clear to Send	Default use for AT command
UART2_RTS	Y3	DI	1.8V	Request to send	
UART2_TXD	U1	DO	1.8V	Transmit Data	
UART2_RXD	W1	DI	1.8V	Receive Data	
BT UART Interface					
BT_UART_CTS	R5	DO	1.8V	Clear to Send	
BT_UART_RTS	U5	DI	1.8V	Request to send	
BT_UART_TXD	T7	DO	1.8V	Transmit Data	
BT_UART_RXD	V7	DI	1.8V	Receive Data	
Debug UART Interface					
DBG_UART_RXD	L5	DI	1.8V	Receive Data	Only used for debug
DBG_UART_TXD	N5	DO	1.8V	Transmit Data	
I2C Interface					
I2C1_SCL	M7	OD	1.8V	I2C1 serial clock; default use for codec	Need pulled up by a 2.2K resistor to VDD_EXT out of the module
I2C1_SDA	P7	OD	1.8V	I2C1 serial data; default use for codec	
I2C2_SCL	AB7	OD	1.8V	I2C2 serial clock; default use for sensor	
I2C2_SDA	Y7	OD	1.8V	I2C2 serial data; default use for sensor	
WLAN I2S Interface					
WL_ I2S_DOUT	K3	DO	1.8V	WLAN I2S data output	
WL_ I2S_DIN	M3	DI	1.8V	WLAN I2S data input	
WL_I2S_CLK	J1	DO	1.8V	WLAN I2S bit clock	
WL_ I2S_WS	G1	DIO	1.8V	WLAN I2S word select	
I2S(PCM) Interface					
I2S_DOUT/ PCM_DOUT	N1	DO	1.8V	I2S/PCM data output	Default is I2S function ,Can be configured PCM function also
I2S_DIN/ PCM_DIN	R1	DI	1.8V	I2S/PCM data input	
I2S_CLK/ PCM_CLK	P3	DO	1.8V	I2S/PCM clock output	
I2S_WS/ PCM_SYNC	T3	DIO	1.8V	I2S word select/ PCM synchronous signal	
I2S_MCLK	L1	DO	1.8V	I2S master clock output	
ADC Interface					

ADC0	AH7	AI	0.1V-1.8V	Analog to digital converter input 0	
ADC1	AF7	AI	0.1V-1.8V	Analog to digital converter input 1	
RGMII Interface					
RGMII_MD_IO	D30	DIO		RGMII MDIO management data	Required 50 Ω impedance
RGMII_MD_CLK	D34	DO		RGMII MDIO management clock	
RGMII _RX_CTL	A35	DI		RGMII receive control	
RGMII _RX_CLK	B36	DI		RGMII receive clock	
RGMII_RX_0	B40	DI		RGMII receive data bit 0	
RGMII_RX_1	A37	DI		RGMII receive data bit 1	
RGMII_RX_2	B38	DI		RGMII receive data bit 2	
RGMII_RX_3	A39	DI		RGMII receive data bit 3	
RGMII _TX_CTL	A33	DO		RGMII transmit control	
RGMII _TX_CLK	B34	DO		RGMII transmit clock	
RGMII_TX_0	A31	DO		RGMII transmit data bit 0	
RGMII_TX_1	B30	DO		RGMII transmit data bit 1	
RGMII_TX_2	A29	DO		RGMII transmit data bit 2	
RGMII_TX_3	B32	DO		RGMII transmit data bit 3	
RGMII_INT_N	C39	DI	1.8V	RGMII PHY interrupt output	
RGMII_RST_N	C29	DO	1.8V	Reset output for RGMII PHY	
RGMII_PWR_EN	D36	DO	1.8V	Used to enable external DC-DC or LDO to supply 2.5V power to RGMII_PWR_IN and external RGMII circuit	
RGMII_PWR_IN	D32	PI	1.8/2.5V	External 2.5V Power input for internal RGMII IO circuits	If not use RGMII function this pin need connect to VDD_EXT out of the module
RGMII_3P3_EN	D38	DO	1.8V	Used to enable external power supply 3.3V power to external RGMII circuit	
PCIE Interface					
PCIE_REFCLK_P	B22	AO		PCIe reference clock plus	Required 90 Ω differential impedance
PCIE_REFCLK_M	A21	AO		PCIe reference clock minus	
PCIE_TX0_M	B18	AO		PCIe transmit0 minus	
PCIE_TX0_P	A17	AO		PCIe transmit0 plus	
PCIE_TX1_M	B20	AO		PCIe transmit1 minus	
PCIE_TX1_P	A19	AO		PCIe transmit1 plus	
PCIE_RX0_M	A25	AI		PCIe receive0 minus	
PCIE_RX0_P	B26	AI		PCIe receive0 plus	
PCIE_RX1_M	A23	AI		PCIe receive1 minus	
PCIE_RX1_P	B24	AI		PCIe receive1 plus	
PCIE_CLKREQ	C21	DO		PCIe clock request	
PCIE_RST	C23	DO	1.8V	PCIe reset	
PCIE_WAKE	C25	DI	1.8V	PCIe wake-up	

WLAN Interface					
WL_SW_CTRL	K49	DO	1.8V	WLAN Switch control	
SDX_TO_WL_CTI	M49	DO	1.8V	WLAN GPIO	
WL_TO_SDX_CTI	L47	DI	1.8V	WLAN GPIO	
BT_EN	N51	DO	1.8V	BT enable	
SLEEP_CLK	J51	DO		WLAN sleep clock output	Only used for WLAN
RF_CLK3	P45	DO		WLAN XTALI output	SDX55 platform WLAN need add external XTALI
WLAN_EN	K45	DO	1.8V	WLAN enable	
WL_LAA_RX	J47	DI	1.8V	WLAN XFEM control for LAA receiver	WLAN RF coexistence signals
WL_PA_MUTING	H45	DO	1.8V	WLAN XFEM control for PA mute	
WL_LAA_AS_EN	L51	DO	1.8V	WLAN LAA AS enable	
WL_LAA_TX_EN	R51	DO	1.8V	WLAN XFEM control LAA enable	
COEX_UART_TXD	BA7	DO	1.8V	LTE&WLAN coexistence data transmit	
COEX_UART_RXD	BA9	DI	1.8V	LTE&WLAN coexistence data receive	
WL_TX_EN	AY14	DI		WLAN XFEM control for WLAN TX enable	
SDIO Interface					
SDIO_VDD	F7	PI	1.8V/2.85V	External 2.85V Power input for SDIO circuit	If not use SD function this pin need connect to VDD_EXT out of the module
SDC_DATA0	B1	DIO	1.8V/2.85V	SD data 0	
SDC_DATA1	C1	DIO	1.8V/2.85V	SD data 1	
SDC_DATA2	D3	DIO	1.8V/2.85V	SD data 2	
SDC_DATA3	F3	DIO	1.8V/2.85V	SD data 3	
SDC_CMD	G5	DO	1.8V/2.85V	SD command output	
SDC_CLK	E5	DO	1.8V/2.85V	SD clock output	
SDC_ DET	E1	DI	1.8V	SD card insertion detect H: SD card is removed L: SD card is inserted	Need pull up to VDD_EXT by a 470K resistor out of the module
SDC_VDD_EN	H7	DO	1.8V	Enable the SD card power out of the module	SD card need add power supply out of the module
PMI Interface					
CHG_SYS_OK	C43	DI		when charger input is inserted PMI output signal to PMU	Only used for the PMI PM8150B
FAULT_N	B44	DIO		used to send/receive the fault condition	SPMI CLK/DATA

				across all PMICs in the chipset	required 50Ω impedance
SPMI_CLK	A47	DO		SPMI communication bus clock signal	
SPMI_DATA	B46	DIO		SPMI communication bus data signal	
GPIO Interface					
GPIO100	H3	DIO	1.8V	General purpose input /output	support wakeup and interrupt function
GPIO101	K7	DIO	1.8V	General purpose input /output	
Other Interface					
EMAC_OUT	AY10	DO	1.8V	1PPS time sync output	
USB_BOOT	D12	DI	1.8V	Module will be forced into USB download mode by connect this PIN to VDD_EXT	
W_DISABLE	AG1	DI	1.8V	Airplane mode control input	Low active
SLEEP_IN	AG5	DI	1.8V	Module sleep Mode control input	
WAKEUP_OUT	AF3	DO	1.8V	Control the external AP Sleep Mode	
CDC_RST_N	AK7	DO	1.8V	Reset the external CODEC	Low active
CDC_INT_N	AM7	DI	1.8V	External CODEC interrupt input	Low active
RF Interface					
RFFE0_CLK	BA11	DO	1.8V	Tunable ANT MIPI CLK	
RFFE0_DATA	BA13	DIO	1.8V	Tunable ANT MIPI DATA	
ANT_CTRL0	BA15	DO	1.8V	Tunable ANT CTRL0	
ANT_CTRL1	AY16	DO	1.8V	Tunable ANT CTRL1	
ANT Interface					
ANT0	AL1	AIO		LTE low/middle/high BAND signal send and receive; N41 signal send and receive; N79 signal diversity receive	617MHz~960MHz 1710MHz~2690MHz 4400MHz~5000MHz
ANT1	BA25	AI		LTE middle/high band signal diversity receive; N41&N77 signal diversity receive	1710MHz~2690MHz 3300MHz~4200MHz
ANT2	BA41	AIO		LTE low/middle/high band signal diversity receive; N79 signal send and receive	617MHz~960MHz 1710MHz~2690MHz 4400MHz~5000MHz
ANT3	AY51	AIO		LTE middle/high BAND signal diversity receive; N41 signal diversity receive; N77 signal send and receive	1710MHz~2690MHz 3300MHz~4200MHz
ANT4	BA33	AIO		N41 signal send and receive; N77 signal diversity receive	2496MHz~2690MHz 3300MHz~4200MHz
ANT5	BA19	AIO		N77 signal send and receive	3300MHz~4200MHz
ANT6	AY1	AI		N79 signal diversity receive; GNSS signal receive ;	1166MHz~1229MHz 1565MHz~1610MHz

					4400MHz~5000MHz
ANT7	BA47	AIO		N79 signal send and receive	4400MHz~5000MHz
RFU Interface					
RFU	AP7,AW17,AW19,AW21,AT45,AP45,AM45, AK45,AG51,AU51,AR51,AN51,AJ51,AL51,AE51,AC51,BA37,BA29,AT49,AP49, AM49,AK49,AH49,AF49			Reserved for future use	

8.1A 5G S-Module Basic Type-L

8.1A.1 Diagram

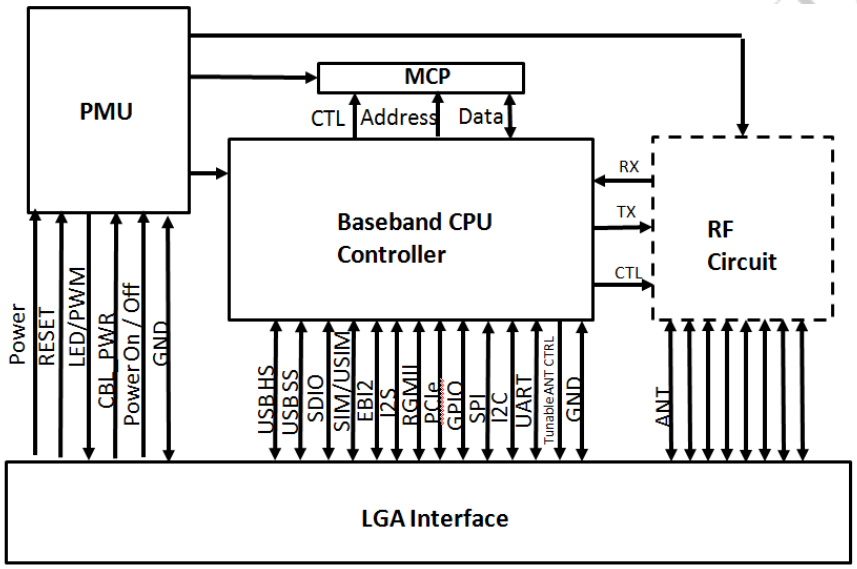


Figure 8-1A 5G S-Module Basic Type-L Diagram

8.1A.2 Pin Layout

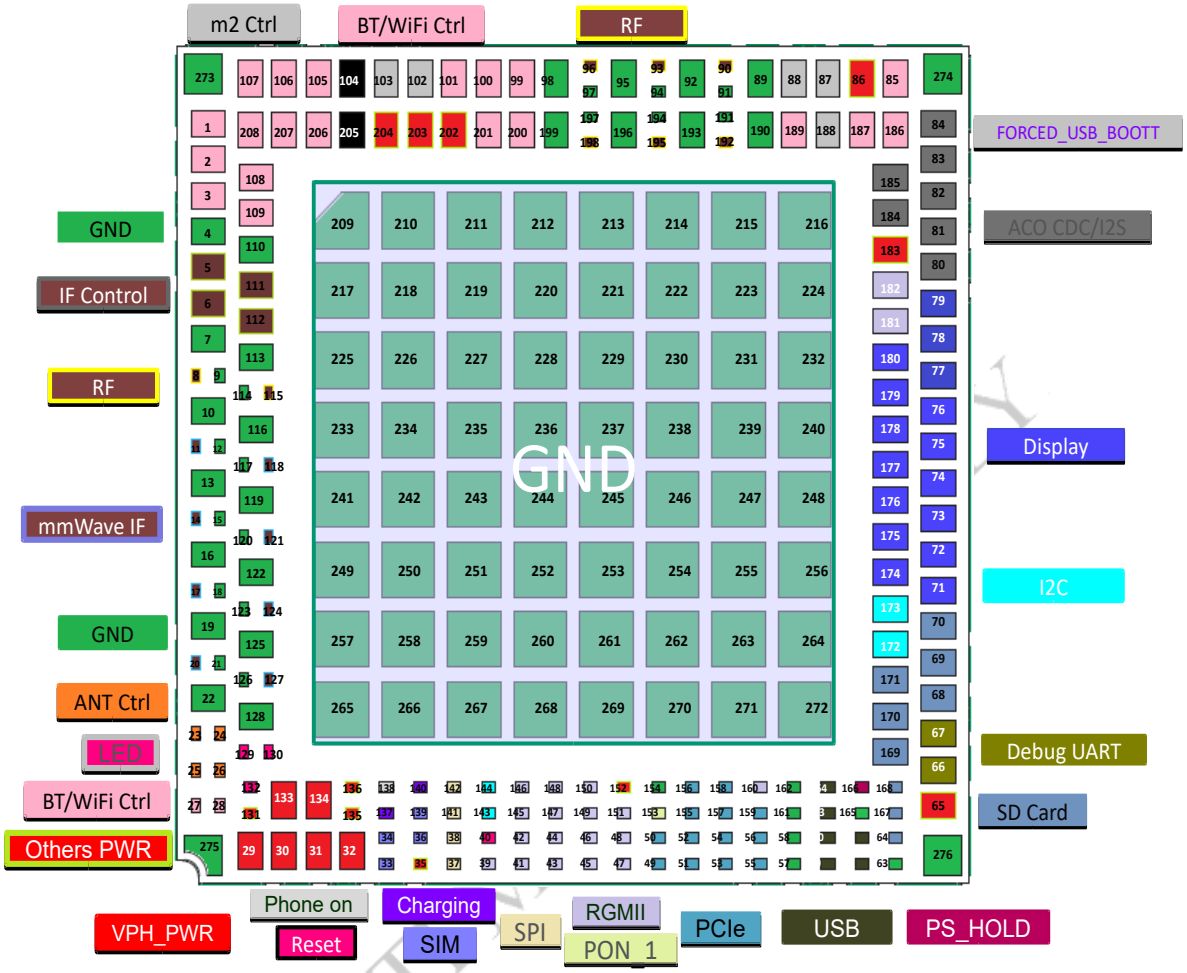


Figure 8-2A 5G S-Module Basic Type-L Pin Layout

8.1A.3 Pin Size

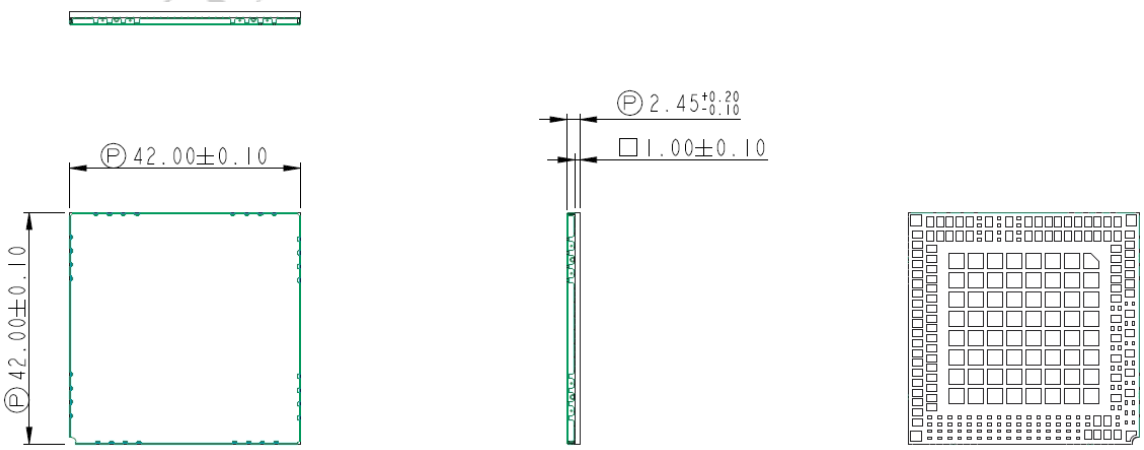


Figure 8-3A 5G S-Module Basic Type-L Pin Size-1

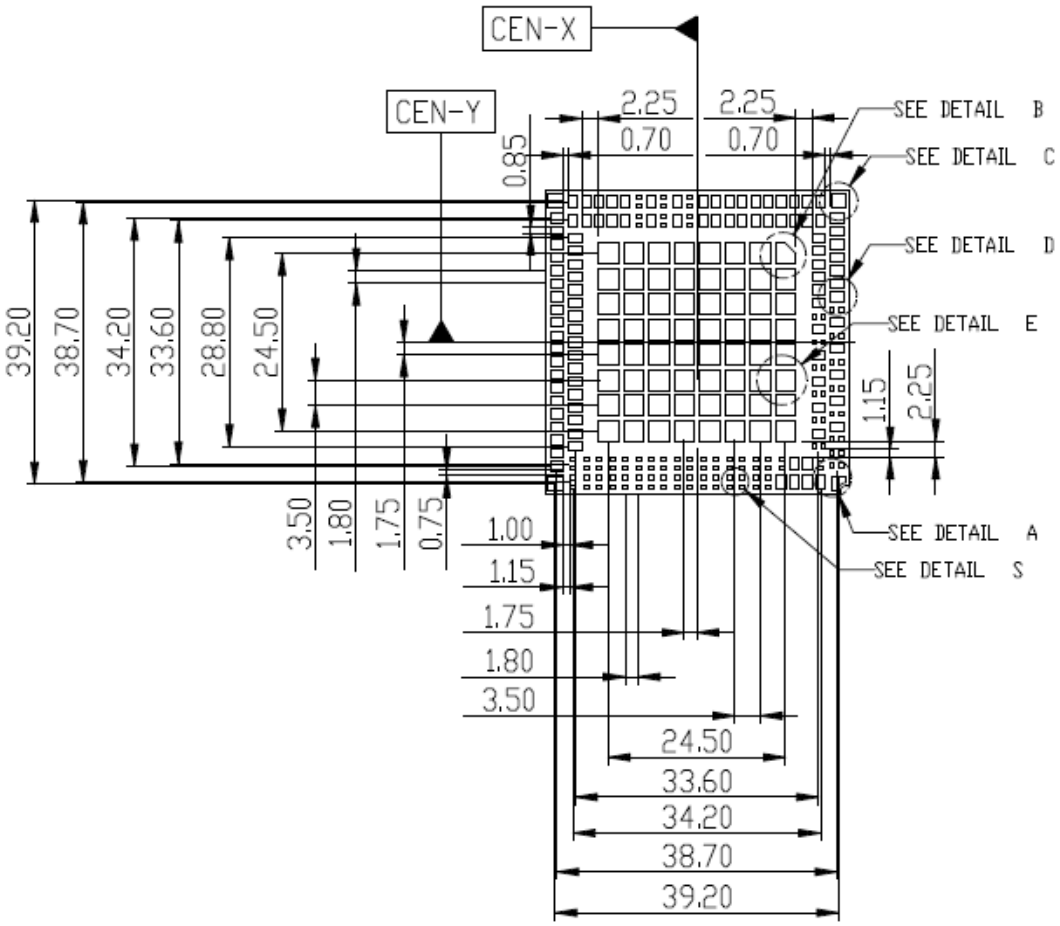


Figure 8-3A 5G S-Module Basic Type-L Pin Size-2

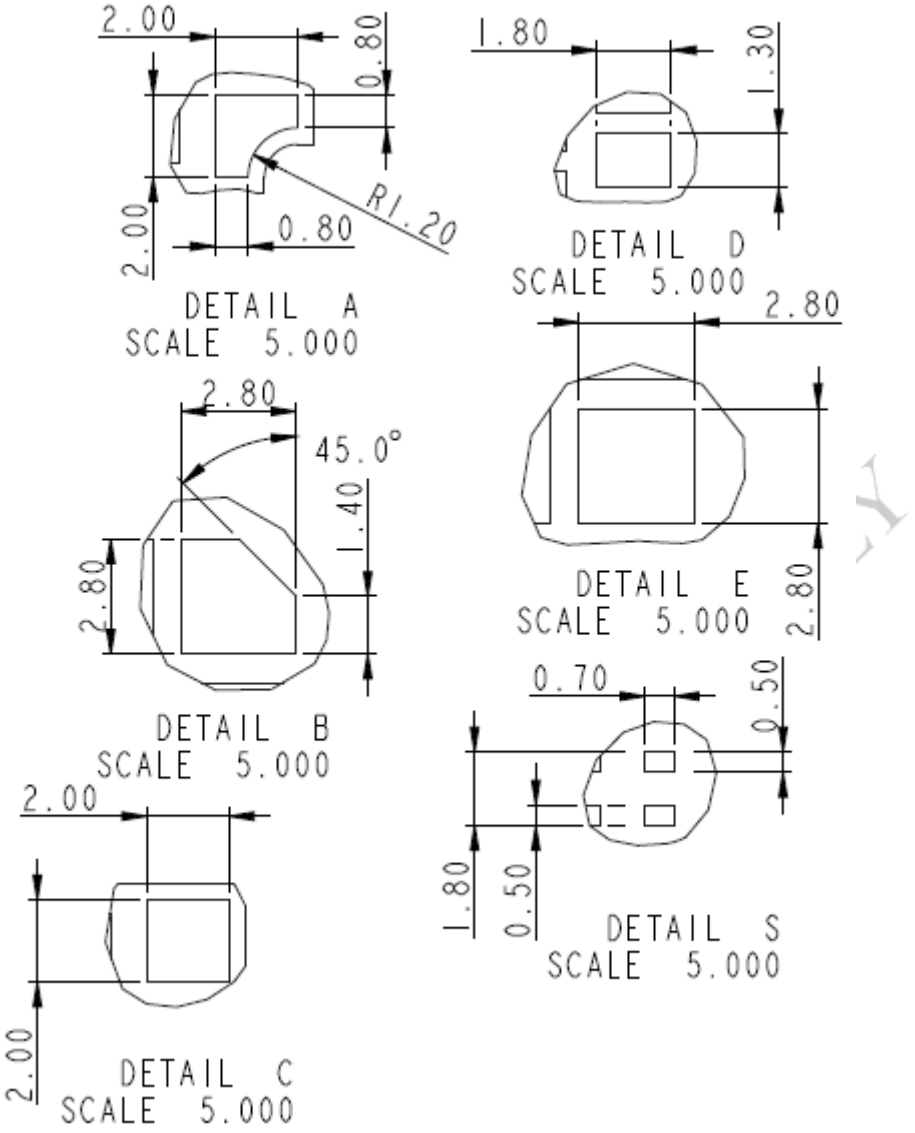


Figure 8-3A 5G S-Module Basic Type-L Pin Size-3

8.1A.4 Pin Definition

Pin name	Pin No.	Default status	Description	Comment
HST_WL_TX_EN	1	DO	For ANT sharing structure(WIFI &WLAN),WLAN_TX_EN and LAA_TX_EN signaling with SDR865	
WL_SEC_IS_S	2	B[1]	I2S for BT	
WL_SEC_I2S_SCK	3	B	I2S for BT wait	
NC	5			
NC	6			

ANT0	8	B	RF Signal ANT output	
NC	11			
NC	14			
NC	17			
NC	20			
SDX_RFFE0_DATA_GRFC1	23	B	Ant Tuner0 Mipi control(Data pin)	
SDX_RFFE0_CLK_GRFC0	24	B	Ant Tuner0 Mipi control(CLK pin)	
RF_CONN_RFFE1_DATA	25	B	Ant Tuner1 Mipi control(Data pin)	
RF_CONN_RFFE1_CLK	26	B	Ant Tuner1 Mipi control(CLK pin)	
SLEEP_CLK	27	DO	Sleep clock control from SDX55 for wifi	1.8
RF_CLK3_WL	28		WIFI	
VPH_PWR_1	29	PI	For LGA Module power, generated by either the charger or battery	3.4V~4.3V
VPH_PWR_2	30	PI	For LGA Module power, generated by either the charger or battery	3.4V~4.3V
VPH_PWR_3	31	PI	For LGA Module power, generated by either the charger or battery	3.4V~4.3V
VPH_PWR_4	32	PI	For LGA Module power, generated by either the charger or battery	3.4V~4.3V
SDX_UIM1_CLK_M2	33	DO	UIM1 clock	1.8
SDX_UIM1_DATA_M2	34	B	UIM1 data	1.8
VDDPX_8_VREF_RGMII	35	PI	Reserve Power Input for RGMII circuits If no use, connect this pin to GND If is used, connect this pin to VREF_RGMII	
SDX_UIM1_PRESENT_M2	36	DI	UIM1 presence detection	1.8

BLSP_SPI_MOSI	37	B	Reserve SPI IF	
BLSP_SPI_CS_N	38	B	Reserve SPI IF	1.8
RGMII_MD_IO	39	B	RGMII – management data	
LGA_RESET	40	DO	The user can generate a required reset by a long keypress to reset PMIC	1.8
RGMII_MD_CLK	41	DO	RGMII – management data clock	
RGMII_TX_CTL	42	DO	RGMII transmit control	
RGMII_TX_3	43	DO	RGMII transmit data bit 3	1.8
RGMII_TX_1	44	DO	RGMII transmit data bit 1	1.8
RGMII_TX_0	45	DO	RGMII transmit data bit 0	1.8
RGMII_TX_2	46	DO	RGMII transmit data bit 2	1.8
RGMII_TX_CLK	47	B	RGMII transmit clock	1.8
RGMII_RESET_N	48	DO	RGMII RESET	1.8
PCIE_RX0_P	49	AIO	PCIe Rx 0 plus	1.8
PCIE_RX0_M	50	AIO	PCIe Rx 0 minus	1.8
PCIE_TX1_M	51	AIO	PCIe Tx 1 minus	1.8
PCIE_TX1_P	52	AIO	PCIe Tx 1 plus	1.8
PCIE_TX0_M	53	AIO	PCIe Tx 0 minus	1.8
PCIE_TX0_P	54	AIO	PCIe Tx 0 plus	1.8
PCIE_WL_WAKE_N	55	B	PCIe wake signal	1.8
PCIE_WL_RESET_N	56	DO	PCIe reset	1.8

USB_SS_TX_M	59	AIO	USB SS Tx minus	1.8
USB_SS_TX_P	60	AIO	USB SS Tx plus	1.8
USB_HS_DP	61	AIO	USB HS data plus	1.8
USB_HS_DM	62	AIO	USB HS data minus	1.8
SDX_SDC_CLK	64	B	SDC clock	1.8
VREG_PX2_DUAL	65	PI	Reserve Power Input for SDIO IF. Connect this pin to L6 (1.8V) if no need SD card function. Connect to Duel Power Supply (1.8V/2.85V) if need SD card function.	1.8V
DBG_UART_RX	66	DI	UART receive data (used for debug)	1.8
DBG_UART_TX	67	DO	UART transmit data – (used for debug)	1.8
SDX_GPIO_98	68	B	Reserve GPIO	1.8
SDX_GPIO_99	69	B	Reserve GPIO	1.8
SDX_GPIO_100	70	B	Reserve GPIO	1.8
EBI2_LCD_RESET_N	71	DO	LCD reset	1.8
EBI2_LCD_CS_N	72	DO	EBI2 LCD chip select	1.8
EBI2_LCD_TE	73	DO	EBI2 LCD tearing effect	1.8
EBI2_AD_4	74	B	EBI2 multiplexed address and data - bit 4	1.8
EBI2_AD_0	75	B	EBI2 multiplexed address and data - bit 0	1.8
EBI2_AD_2	76	B	EBI2 multiplexed address and data - bit 2	1.8
EBI2_AD_6	77	B	EBI2 multiplexed address and data - bit 6	1.8
EBI2_AD_1	78	B	EBI2 multiplexed address and data - bit 1	1.8

EBI2_AD_7	79	B	EBI2 multiplexed address and data - bit 7	1.8
CDC_RESET_N	80	B	GPIO reserve for audio interface	1.8
CDC_INT1_N	81	B	GPIO reserve for audio interface	1.8
PRI_I2S_SCK	82	B	I2S reserve for Primary audio interface , MI2S clock	1.8
PRI_I2S_WS	83	B	I2S reserve for Primary audio interface , MI2S word select	1.8
I2S_MCLK	84	DO	I2S reserve for Audio master clock	1.8
RF_COEX_UART_TX	85	DO	Reserved for WIFI QCA639X_LTE_COEX_TXD (LTE Co-existence)	
VREG_L6E_BB_1P8	86	PO	WIFI power	1.8
M2_DPR_GPIO_104	87	B	GPIO Reserved General Purpose I/O The function of these pins haven't been defined.	
M2_WAKUP_HOST	88	B	GPIO Reserved General Purpose I/O The function of these pins haven't been defined.	
ANT6	90	B	RF Signal ANT6 output	
ANT3	93	B	RF Signal ANT3 output	
ANT4	96	B	RF Signal ANT4 output	
SDX_TO_WL_CTI	99	B-PD[2]	WL_GPIO	
NC	100			
NC	101			
M2_W_DISABLE2	102	B	GPIO Reserved General Purpose I/O The function of these pins haven't been defined.	
M2_COEX3	103	B	GPIO Reserved General Purpose I/O The function of these pins haven't been defined.	
Non connect	104		Non connect	
BT_UART_RTS_N	105	DO	UART for BT	

BT_UART_RX	106	DI	UART for BT	
WL_BT_EN	107	DI	BT Enable	
WL_SEC_I2S_DOUT	108	B	I2S for BT wait	
WL_SEC_I2S_DIN	109	B	I2S for BT	
NC	111			
NC	112			
ANT7	115	B	RF Signal ANT7 output	
NC	118			
NC	121			
NC	124			
NC	127			
GPIO_SDX55_RLED	129	DO	For R LED Control by SDX55	
GPIO_03_LED	130	DI	For RGB LED control by PMX55	1.8
VREG_L10E_3P1	131	PO	For USB MUX Switch Power	3.1
GPIO_05_LED	132	DI	For RGB LED control by PMX55	1.8
VPH_PWR_5	133	PI	For LGA Module power, generated by either the charger or battery	3.4V~4.3V
VPH_PWR_6	134	PI	For LGA Module power, generated by either the charger or battery	3.4V~4.3V
VREG_L11E_UIM1_1P8	135	PO	To SIM POWER	1.8/2.85
VREF_RGMII	136	AO/LV	VREF output and PMX55 GPIO_09 is hidden behind this function	
CHRGR_SYS_OK_N	137	DI	User asserts USB cable to initiate PMIC cable power-on	1.8
PHONE_ON_N	138	DI PU[3]	User asserts key switch to initiate power-on	
SDX_UIM1_RESET_N_M	139		SIM1 reset	

2				
CHRGR_USB_PHY_ON	140	DI	The VBUS_DET input pin is used to detect the USB connection status to the modem by monitoring the USB VBUS.	
BLSP_SPI_CLK	141	B	Reserve SPI IF SPI clock	1.8
BLSP_SPI_MISO	142	DO	Reserve SPI IF SPI master in, slave out	
I2C_SDA	143	B	Reserve for charger I2C (Need External pull-up 2.2K on 1.8V, if need to use this I2C)	1.8
I2C_SCL	144	B	Reserve for charger I2C (Need External pull-up 2.2K on 1.8V, if need to use this I2C)	1.8
RGMII_RX_2	145	DI	RGMII receive data bit 2	
RGMII_RX_CLK	146	DI	RGMII receiver clock	
RGMII_RX_CTL	147	DI	RGMII receiver control	
RGMII_RX_0	148	DI	RGMII receive data bit 0	
RGMII_RX_1	149	DI	RGMII receive data bit 1	
RGMII_RX_3	150	DI	RGMII receive data bit 3	
RGMII_Int_N	151	B	RGMII_Int_N	1.8
VREG_DBU3_2P5	152	PI	RGMII Power Reserved, If RGMII function no used, connect this pin to VREG_L6E_BB_1P8. If use, need apply 2.5V power supply on this pin.	1.8 or 2.5
PON_1	153	DI	User to drive high for to initiate power-on. Reserve for Auto Power On Design. User to drive high for > 5ms to initiate power-on, so, connect this pin to VPH_PWR and let P138 to floating if need auto power on.	
PCIE_RX1_P	155	AIO	PCIe Rx 1 plus	1.8

PCIE_RX1_M	156	AIO	PCIe Rx 1 minus	1.8
PCIE_REFCLK_P	157	AIO	PCIe reference clock – plus	1.8
PCIE_REFCLK_M	158	AIO	PCIe reference clock – minus	1.8
PCIE_WL_CLKREQ_N	159	DO	PCIe clock request	1.8
EMAC_PPS0_OUT	160			
USB_SS_RX_P	163	AIO	USB SS Rx plus	1.8
USB_SS_RX_M	164	AIO	USB SS Rx minus	1.8
SDX_PS_HOLD	166	DO	Monitor Power-supply hold signal to PMIC (Just for debug used) The purpose of SDX_PS_HOLD pin is just for measurement, what used for monitor whether the power on process has been completed. No additional control is required. If do not need to use it, please keep it empty or reserve 1 test point.	1.8
SDX_SDC_DATA_1	167	B	SDIO IF reserve SDC data bit 1	1.8
SDX_SDC_DATA_3	168	B	SDIO IF reserve SDC data bit 3	1.8
SDX_SDC_DATA_0	169	B	SDIO IF reserve SDC data bit 0	1.8
SDX_SDC_DATA_2	170	B	SDIO IF reserve SDC data bit 2	1.8
SDX_SDC_CMD	171	B	SDIO IF reserve	1.8
BLSP3_I2C_SCL	172	DO	I2C reserve for TP I2C	1.8
BLSP3_I2C_SDA	173	B	I2C reserve for TP I2C	1.8
EBI2_AD_8	174	DO	EBI2 multiplexed address and data - bit 8	1.8
EBI2_WE_N	175	DO	EBI2 write enable	1.8

EBI2_OE_N	176	DO	EBI2 output enable	1.8
EBI2_AD_5	177	B	EBI2 multiplexed address and data - bit 5	1.8
EBI2_CLE	178	DO	EBI2 command latch enable	1.8
EBI2_AD_3	179	B	EBI2 multiplexed address and data - bit 3	1.8
DISP_BKLT_EN	180	DO	For Backlight_PWM Control	1.8
RGMII_VREG_PX_EN	181	B	RGMII IO control pin	
RGMII_VREG_3P3_EN	182	B	RGMII IO control pin	
VREG_L6E_BB_1P8	183	PO	Reserve Power for Audio codec Connector this pin for pin65, if no use SD card function.	1.8
PRI_I2S_DIN	184	B	I2S reserve for Audio codec	1.8
PRI_I2S_DOUT	185	B	I2S reserve for Audio codec	1.8
RF_COEX_UART_RX	186	DI	Reserved for WIFI QCA639X _LTE_COEX_RXD (LTE Co-existence)	
WLAN_EN	187	DO	WL_EN for QCA639X	
FORCED_USB_BOOT	188	DI	Forces boot DL from HS USB	H Active
SDR_GRFC2	189		For ANT sharing structure(WIFI &WLAN),WLAN_TX_EN and LAA_TX_EN signaling with SDR865	
ANT1	192	B	RF Signal ANT1 output	
ANT5	195	B	RF Signal ANT5 output	
ANT2	198	B	RF Signal ANT2 output	
WL_TO_SDX_CTI	200		WIFI UART(WL_UART_RTS_N_GPIO)	
WL_PA_MUTING	201		For ANT sharing structure(WIFI &WLAN) to prevent component damage if WLAN & LTE TX power both too high	

VREG_S3E_0P824	202	PO	Power supply input for WIFI	0.82
VREG_S4E_1P904	203	PO	Power supply input for WIFI	1.9
VREG_S2E_1P224	204	PO	Power supply input for WIFI	1.22
NC	205		NC	
BT_UART_CTS_N	206	DI	UART for BT	
BT_UART_TX	207	DO	UART for BT	
WL_SW_CTRL	208	DO	SW_CTRL	
PAD GND	209~276	-	PAD GND	
RF GND	4,7,9,10,12,13,15,16,18,19,21,22,57,58,63,89,91,92,94,95,97,98,110,113,114,116,117,119,120,122,123,125,126,128,154,161,162,165,190,191,193,194,196,197,199	-	RF GND	
B[1] : Bidirectional digital with CMOS input PD[2]: Pull-Down PU[3]: Pull-Up				

8.2 5G S-Module Basic Type-M

8.2.1 Diagram

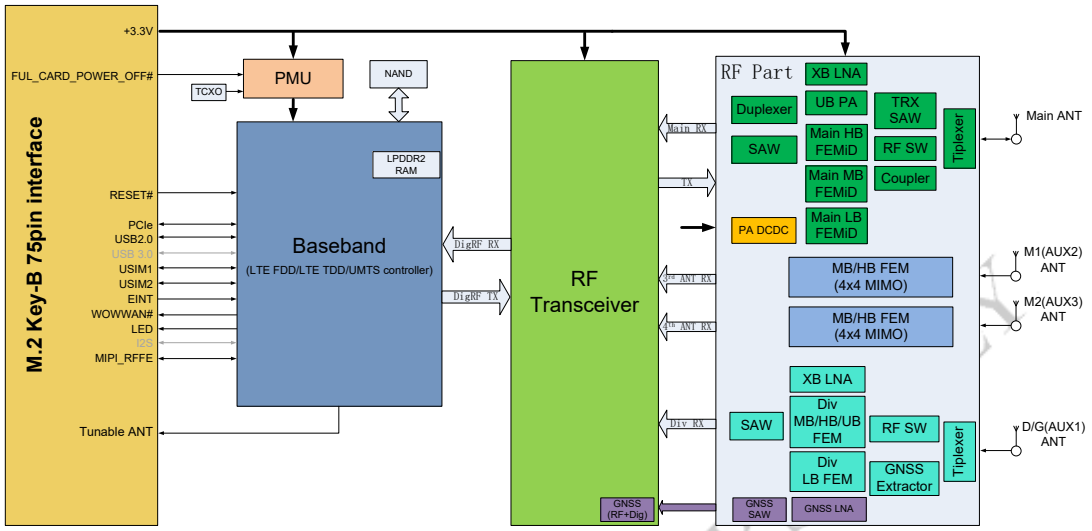


Figure 8-4 5G S-Module Basic Type-M Diagram

8.2.2 Pin Layout

74	+3.3V	CONFIG_2	75
72	+3.3V	NC	73
70	+3.3V	GND	71
68	ANT_CONFIG(1.8V)/ Reserved	CONFIG_1	69
66	SIM1_DETECT(1.8V)	RESET#(1.8V)	67
64	COEX1(1.8V)	ANTCTL3(1.8V)	65
62	COEX2(1.8V)	ANTCTL2(1.8V)	63
60	COEX3(1.8V)	ANTCTL1(1.8V)	61
58	RFE_RFFE_SDATA	ANTCTL0(1.8V)	59
		GND	57

56	RFE_RFFE_SCLK		
54	PEWAKE# (3.3V)	REFCLKP	55
52	CLKREQ# (3.3V)	REFCLKN	53
50	PERST# (3.3V)	GND	51
48	UIM2_PWR	PERp0	49
46	UIM2_RESET	PERn0	47
44	UIM2_CLK	GND	45
42	UIM2_DATA	PETp0	43
40	SIM2_DETECT(1.8V)	PETn0	41
38	Reserved	GND	39
36	UIM1_PWR	USB3.0-Rx+/Reserved	37
34	UIM1_DATA	USB3.0-Rx-/Reserved	35
32	UIM1_CLK	GND	33
30	UIM1_RESET	USB3.0-Tx+/Reserved	31
28	I2S_WA(1.8V)/Reserved	USB3.0-Tx-/Reserved	29
26	W_DISABLE2#(3.3/1.8V)	GND	27
24	I2S_TX(1.8V)/Reserved	DPR(3.3/1.8V)	25
22	I2S_RX/Reserved	WOWWAN#(1.8V)	23
20	I2S_CLK/Reserved	CONFIG_0	21
	Notch	Notch	
	Notch	Notch	
	Notch	Notch	

	Notch		
	Notch	Notch	
10	LED1#(3.3V OD)	GND	11
8	W_DISABLE1#(3.3/1.8V)	USB D-/Reserved	9
6	FUL_CARD_POWER_OFF#(3.3/1.8V)	USB D+/Reserved	7
4	+3.3V	GND	5
2	+3.3V	GND	3
		CONFIG_3	1

Figure 8-5 5G S-Module Type-M Pin Layout

8.2.3 Pin Size

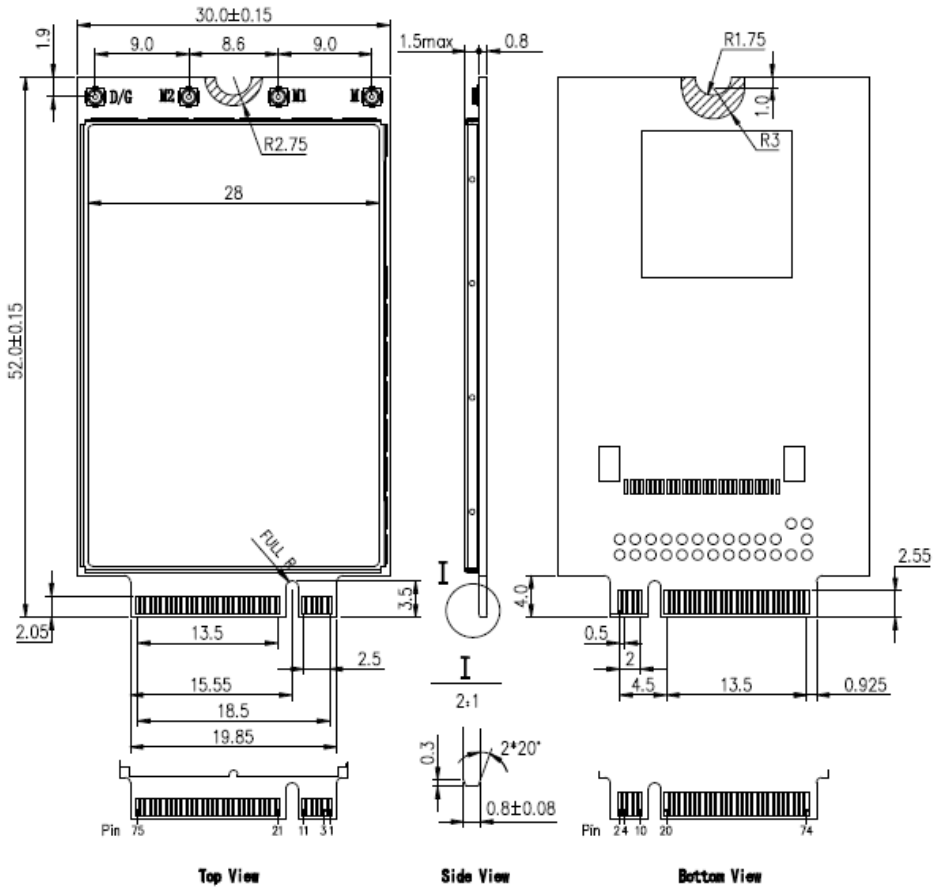


Figure 8-6 5G S-Module Type-M Pin Size

8.2.4 Pin Definition

Table 8-2 5G S-Module Type-M Pin Definition

Pin	Pin Name	I/O	Reset Value	Pin Description	Type
1	CONFIG_3	DO	NC	NC, 5G M.2 module is configured as the WWAN – PCIe, USB3.0 interface type	
2	+3.3V	PI	-	Power input	Power Supply
3	GND	-	-	GND	Power Supply
4	+3.3V	PI	-	Power input	Power Supply
5	GND	-	-	GND	Power Supply
6	FULL_CARD_ POWER_OFF#	DI	PU[1]	Power enable, Module power on input, internal pull up	CMOS 3.3/1.8V
7	USB D+	I/O		USB Data Plus, Reserved	0.3---3V
8	W_DISABLE1#	DI	PD[2]	WWAN Disable, active low	CMOS 3.3/1.8V
9	USB D-	I/O		USB Data Minus, Reserved	0.3---3V
10	LED1#	OD	T[3]	System status LED, Output open drain, CMOS 3.3V	CMOS 3.3V
11	GND	-	-	GND	Power Supply
12	Notch			Notch	
13	Notch			Notch	
14	Notch			Notch	
15	Notch			Notch	
16	Notch			Notch	
17	Notch			Notch	
18	Notch			Notch	
19	Notch			Notch	
20	I2S_CLK	DO	PD	I2S Serial clock, Reserved	CMOS 1.8V
21	CONFIG_0		NC	NC, 5G M.2 module is configured as the WWAN – PCIe, USB3.0 interface type	
22	I2S_RX	DI	PD	I2S Serial receive data, Reserved	CMOS 1.8V
23	WOWWAN#	DO	PD	Wake up host, Reserved	CMOS 1.8V

Pin	Pin Name	I/O	Reset Value	Pin Description	Type
24	I2S_TX	DO	PD	I2S Serial transmit data, Reserved	CMOS 1.8V
25	DPR	DI	PD	Body SAR Detect, active low	CMOS 3.3/1.8V
26	W_DISABLE2#	DI	PD	GNSS disable, active low, Reserved	CMOS 3.3/1.8V
27	GND	-	-	GND	Power Supply
28	I2S_WA	DO	PD	I2S Word alignment/select, Reserved	CMOS 1.8V
29	USB3.0_TX-	DO		USB3.0 Transmit data minus, Reserved	
30	UIM_RESET	DO	L	SIM reset signal	1.8V/3V
31	USB3.0_TX+	DO		USB3.0 Transmit data plus, Reserved	
32	UIM_CLK	DO	L	SIM clock Signal	1.8V/3V
33	GND	-	-	GND	Power Supply
34	UIM_DATA	DIO	L	SIM data input/output	1.8V/3V
35	USB3.0_RX-	DI		USB3.0 receive data minus, Reserved	
36	UIM_PWR	DO		SIM power supply, 3V/1.8V	1.8V/3V
37	USB3.0_RX+	DI		USB3.0 receive data plus, Reserved	
38	NC			Reserved	
39	GND	-	-	GND	Power Supply
40	SIM2_DETECT	DI	PD	SIM2 Detect, internal pull up(390KΩ), active high	CMOS 1.8V
41	PETn0	DO		PCIe TX Differential signals Negative	
42	UIM2_DATA	DIO	L	SIM2 data input/output	1.8V/3V
43	PETp0	DO		PCIe TX Differential signals Positive	
44	UIM2_CLK	DO	L	SIM2 clock Signal	1.8V/3V
45	GND	-	-	GND	Power Supply
46	UIM2_RESET	DO	L	SIM2 reset signal	1.8V/3V
47	PERn0	DI		PCIe RX Differential signals Negative	
48	UIM2_PWR	DO		SIM2 power supply, 3V/1.8V	1.8V/3V
49	PERp0	DI		PCIe RX Differential signals Positive	
50	PERST#	DI	PU	Asserted to reset module PCIe interface default. If module went into core dump, it	CMOS 3.3V

Pin	Pin Name	I/O	Reset Value	Pin Description	Type
				will reset whole module, not only PCIe interface. Active low, internal pull up(10KΩ)	
51	GND	-	-	GND	Power Supply
52	CLKREQ#	DO	PU	Asserted by device to request a PCIe reference clock be available (active clock state) in order to transmit data. It also used by L1 PM Sub states mechanism, asserted by either host or device to initiate an L1 exit. Active low, internal pull up(10KΩ)	CMOS 3.3V
53	REFCLKN	DI		PCIe Reference Clock signal Negative	
54	PEWAKE#	DO	L	Asserted to wake up system and reactivate PCIe link from L2 to L0, it depends on system whether supports wake up functionality. Active low, open drain output and should add external pull up on platform	CMOS 3.3V
55	REFCLKP	DI		PCIe Reference Clock signal Positive	
56	RFFE_SCLK	DO	PD	MIPI Interface Tunable ANT, RFFE clock	CMOS 1.8V
57	GND			GND	Power Supply
58	RFFE_SDATA	DIO	PD	MIPI Interface Tunable ANT, RFFE data	CMOS 1.8V
59	ANTCTL0	DO	L	Tunable ANT CTRL0	CMOS 1.8V
60	COEX3	DIO	PD	Wireless Coexistence between WWAN and Wi-Fi/BT modules, based on BT-SIG coexistence protocol. COEX_EXT_FTA, Reserved	CMOS 1.8V
61	ANTCTL1	DO	PD	Tunable ANT CTRL1	CMOS 1.8V
62	COEX_RXD	DI	T	Wireless Coexistence between WWAN and Wi-Fi/BT modules, based on BT-SIG coexistence protocol. UART receive	CMOS 1.8V

Pin	Pin Name	I/O	Reset Value	Pin Description	Type
				signal(WWAN module side), Reserved	
63	ANTCTL2	DO	PD	Tunable ANT CTRL2	CMOS 1.8V
64	COEX_TXD	DO	T	Wireless Coexistence between WWAN and Wi-Fi/BT modules, based on BT-SIG coexistence protocol. UART transmit signal(WWAN module side), Reserved	CMOS 1.8V
65	ANTCTL3	DO	PD	Tunable ANT CTRL3	CMOS 1.8V
66	SIM1_DETECT	DI	PD	SIM1 Detect, internal pull up(390KΩ), active high	CMOS 1.8V
67	RESET#	DI	PU	WWAN reset input, internal pull up(10KΩ), active low	CMOS 1.8V
68	ANT_CONFIG/ Reserved	DI	PD	Host antenna configuration detect, internal pull up(100KΩ), Reserved	CMOS 1.8V
69	CONFIG_1	DO	GND	GND, 5G M.2 module is configured as the WWAN – PCIe, USB3.0 interface type	
70	+3.3V	PI	-	Power input	Power Supply
71	GND	-	-	GND	Power Supply
72	+3.3V	PI	-	Power input	Power Supply
73	NC	-	-	NC	Power Supply
74	+3.3V	PI	-	Power input	Power Supply
75	CONFIG_2	DO	NC	NC, 5GM.2 module is configured as the WWAN – PCIe, USB3.0 interface type	
PD[1]: Pull-Down PU[2]: Pull-Up T[3]: Tristate					

8.3 5G S-Module Smart Type

8.3.1 Diagram

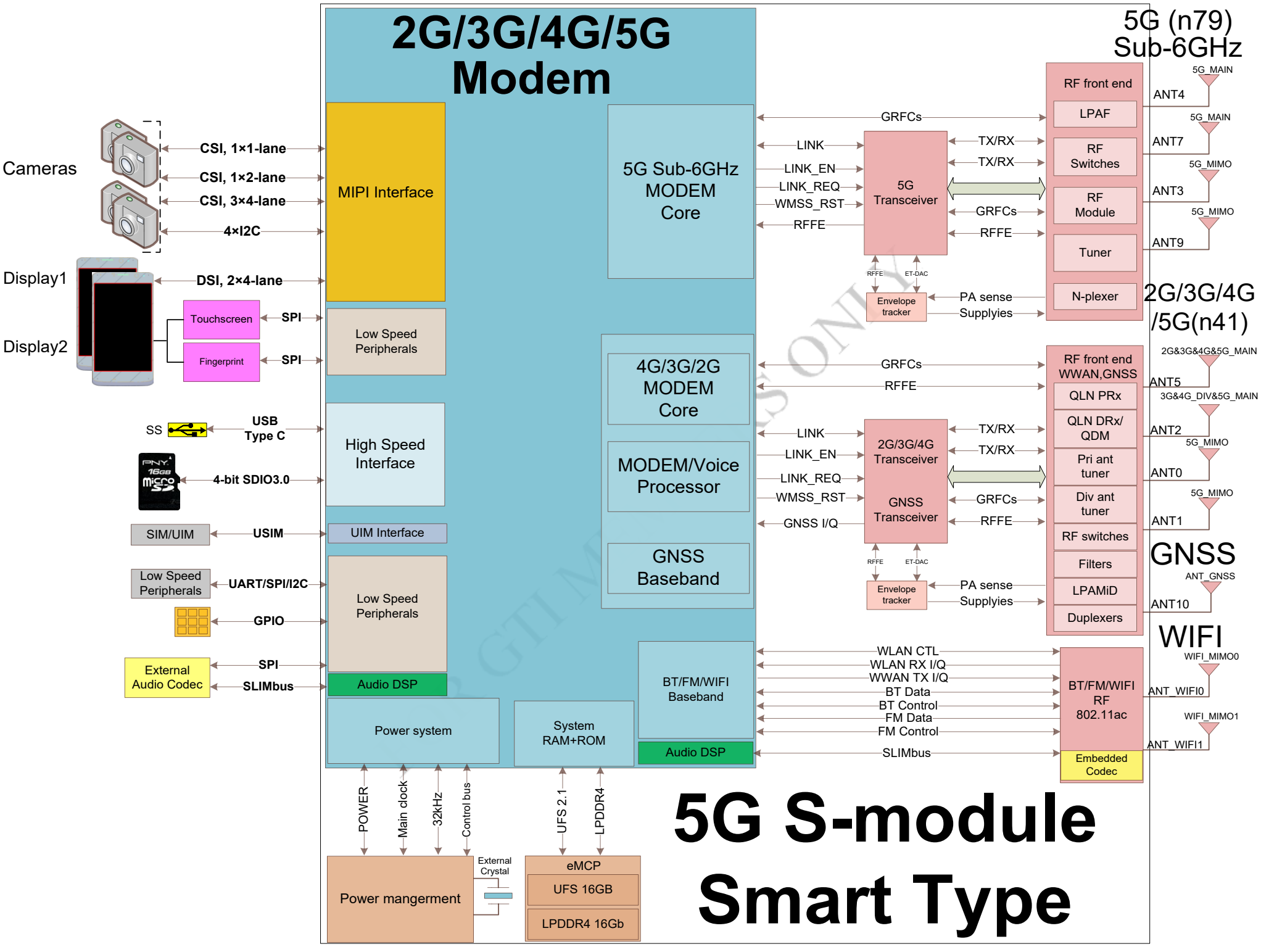


Figure 8-7 5G S-Module Smart Type Diagram

8.3.2 Pin Layout

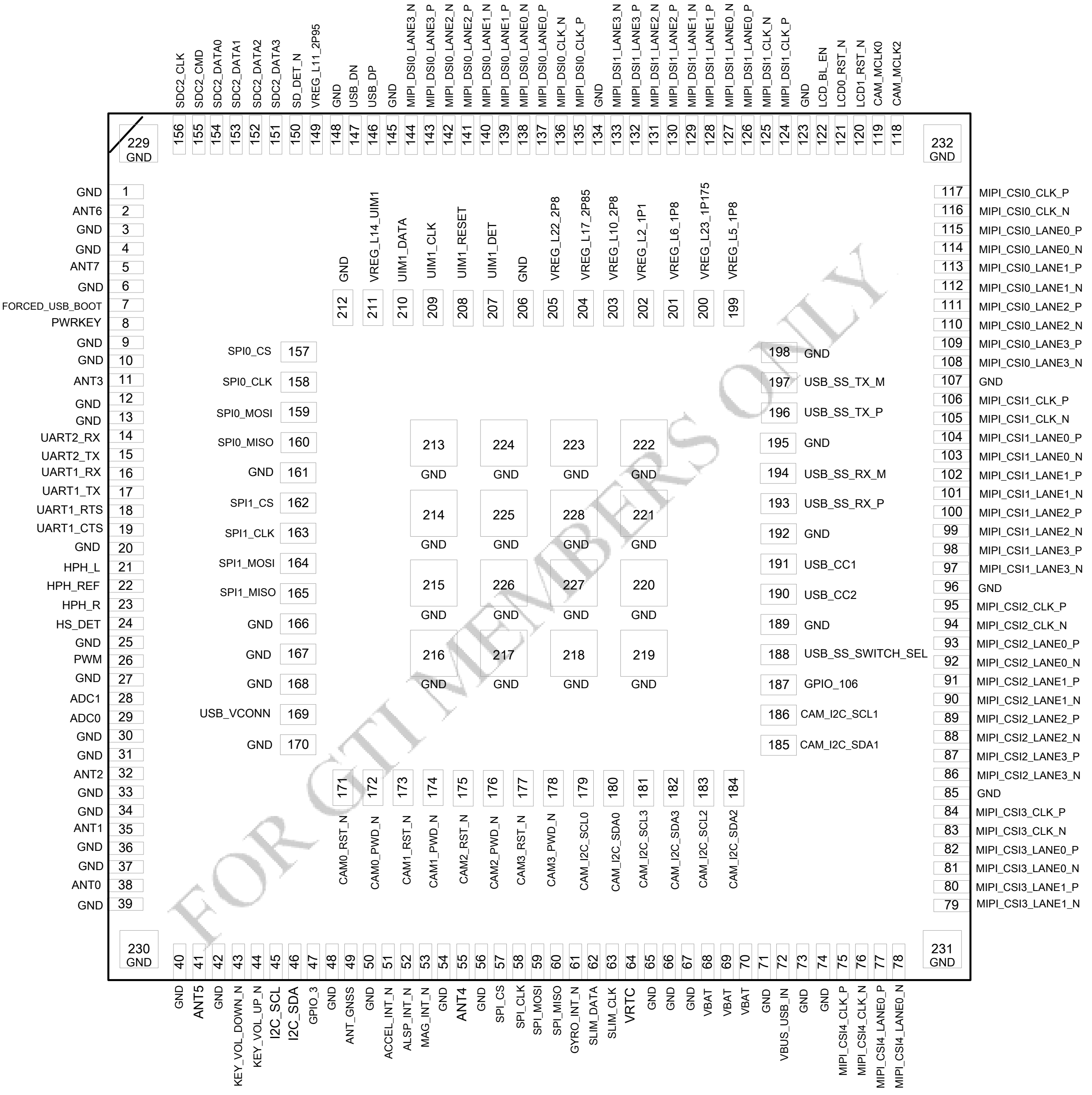


Figure 8-8 5G S-Module Smart Type Pin Layout

8.3.3 Pin Size

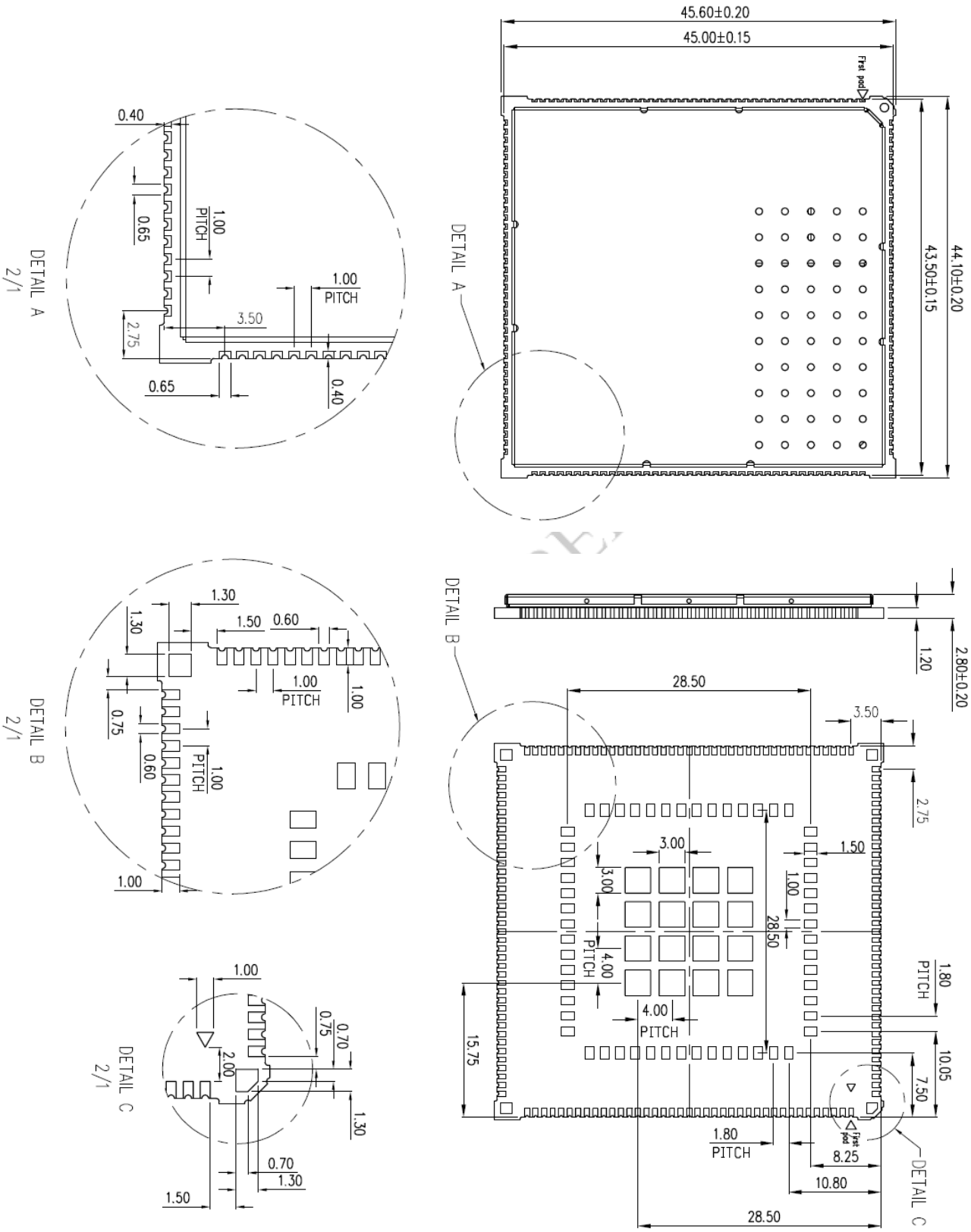


Figure 8-9 5G S-Module Smart Type Pin Size

8.3.4 Pin Definition

Table 8-3 5G S-Module Smart Type Pin Definition

Pin name	Pin No.	Default status	Description	Comment
Power supply				
VBAT	73,74,75	PI	Main power supply, voltage range: 3.4～4.2 V.	
VREG_L22_2P8	4	PO	AVDD power for main/auxiliary cameras	
VREG_L17_2P85	5	PO	Analog power for LCD and cameras	
VREG_L10_2P8	6	PO	Main power for touch-panel and sensors	
VREG_L2_1P1	8	PO	Digital power for main camera	
VREG_L6_1P8	10	PO	Digital 1.8V for external sensor, which would be turned off when the module has been in the sleep mode.	
VREG_L23_1P175	11	PO	Digital power for the auxiliary camera	
VREG_L5_1P8	12	PO	Digital power for the GPIO, always active even in the sleep mode	
VRTC	63	PIO	Coin cell battery or backup battery	
GND				
GND	1,3,4,6,9,10,12,13,16,17,19,20,25,27,28,30,31,33,34,36,37,39,40,42,48,50,54,56,61,70,71,72,76,85,96,107,123,134,145,148,169,181,189,192,195,198,206,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232	P	Ground	
USB TYPE-C interface				
VBUS_USB_IN	77,78	P	Valid USB detection input	
USB_DN	147	DIO	Negative line of the differential, bi-directional USB signal.	
USB_DP	146	DIO	Positive line of the differential, bi-directional USB signal.	
USB_VCONN	170	AI	Power input for type C connection in the DFP mode.	
USB_SS_SWITCH_SEL	188	DO	USB Type C switch selection	

USB_CC2	190	AIO	USB Type C configuration 2	
USB_CC1	191	AIO	USB Type C configuration 1	
USB_SS_RX_P+	193	AI	USB super-speed+ (10Gbps) receive-plus	
USB_SS_RX_M+	194	AI	USB super-speed+ (10Gbps) receive-minus	
USB_SS_TX_P+	196	AO	USB super-speed+ (10Gbps) transmit-plus	
USB_SS_TX_M+	197	AO	USB super-speed+ (10Gbps) transmit-minus	
UIM card interface				
UIM1_DETECT	207	DI	USIM card detecting input.	
UIM1_RESET	208	DO	USIM Reset output	
UIM1_CLK	209	DO	USIM clock output	
UIM1_DATA	210	DIO	USIM Card data I/O	
VREG_L14_UIM1	211	P	Power output for USIM card, the voltage depends on the USIM card. Its output current is up to 50mA.	
SDIO/SD interface				
VREG_L11_2P95	149	P	Voltage of data signal of the SD card	
SDC2_CLK	156	DO	SD clock output	
SDC2_CMD	155	DIO	SD command output	
SDC2_DATA0	154	DIO	SD data 0	
SDC2_DATA1	153	DIO	SD data 1	
SDC2_DATA2	152	DIO	SD data 2	
SDC2_DATA3	151	DIO	SD data 3	
SD_DET_N	150	DI	SD card insertion detect H: SD card is removed L: SD card is inserted	
SPI interface-				
SPI_CS	57	DOH	SPI chip select	
SPI_CLK	58	DOL	SPI clock	
SPI_MOSI	59	DOL	Master output slaver input	
SPI_MISO	60	DI,PD	Master input slaver output	
SPI0_MOSI	159	DOL	Master output slaver input 0	
SPI0_MISO	160	DI,PD	Master input slaver output 0	
SPI0_CS	157	DOH	SPI chip select 0	
SPI0_CLK	158	DOL	SPI clock 0	
SPI1_MOSI	165	DOL	Master output slaver input 1	
SPI1_MISO	166	DI,PD	Master input slaver output 1	

SPI1_CS	163	DOH	SPI chip select 1	
SPI1_CLK	164	DOL	SPI clock 1	
Display interface				
MIPI_DSI0_CLK_P	135	DO	LCD0 MIPI interface	
MIPI_DSI0_CLK_N	136	DO		
MIPI_DSI0_LANE0_P	137	DO		
MIPI_DSI0_LANE0_N	138	DO		
MIPI_DSI0_LANE1_P	139	DO		
MIPI_DSI0_LANE1_N	140	DO		
MIPI_DSI0_LANE2_P	141	DO		
MIPI_DSI0_LANE2_N	142	DO		
MIPI_DSI0_LANE3_P	143	DO		
MIPI_DSI0_LANE3_N	144	DO		
MIPI_DSI1_CLK_P	124	DO	LCD1 MIPI interface	
MIPI_DSI1_CLK_N	125	DO		
MIPI_DSI1_LANE0_P	126	DO		
MIPI_DSI1_LANE0_N	127	DO		
MIPI_DSI1_LANE1_P	128	DO		
MIPI_DSI1_LANE1_N	129	DO		
MIPI_DSI1_LANE2_P	130	DO		
MIPI_DSI1_LANE2_N	131	DO		
MIPI_DSI1_LANE3_P	132	DO		
MIPI_DSI1_LANE3_N	133	DO		
LCD1_RST_N	120	DO	LCD1 reset output	
LCD0_RST_N	121	DO	LCD0 reset output	
LCD0_BL_EN	122	DO	LCD0 backlight enable	
LCD1_BL_EN	119	DO	LCD1 backlight enable	
TS0_INT	161	DI	Touch screen0 interrupt input	
TS0_RST	162	DO	Touch screen0 reset output	
TS1_INT/FP_INT	167	DI	Touch screen1 interrupt input/ Finger print interrupt 1	
TS1_RST/FP_RST	168	DO	Touch screen1 reset output/ Finger print reset output	
Camera interface				
MIPI_CSI0_LANE3_N	108	DI	Camera0 MIPI interface	
MIPI_CSI0_LANE3_P	109	DI		
MIPI_CSI0_LANE2_N	110	DI		
MIPI_CSI0_LANE2_P	111	DI		
MIPI_CSI0_LANE1_N	112	DI		

MIPI_CSI0_LANE1_P	113	DI		
MIPI_CSI0_LANE0_N	114	DI		
MIPI_CSI0_LANE0_P	115	DI		
MIPI_CSI0_CLK_N	116	DI		
MIPI_CSI0_CLK_P	117	DI		
MIPI_CSI1_LANE3_N	97	DI	Camera1 MIPI interface	
MIPI_CSI1_LANE3_P	98	DI		
MIPI_CSI1_LANE2_N	99	DI		
MIPI_CSI1_LANE2_P	100	DI		
MIPI_CSI1_LANE1_N	101	DI		
MIPI_CSI1_LANE1_P	102	DI		
MIPI_CSI1_LANE0_N	103	DI		
MIPI_CSI1_LANE0_P	104	DI		
MIPI_CSI1_CLK_N	105	DI		
MIPI_CSI1_CLK_P	106	DI		
MIPI_CSI2_LANE3_N	86	DI	Camera2 MIPI interface	
MIPI_CSI2_LANE3_P	87	DI		
MIPI_CSI2_LANE2_N	88	DI		
MIPI_CSI2_LANE2_P	89	DI		
MIPI_CSI2_LANE1_N	90	DI		
MIPI_CSI2_LANE1_P	91	DI		
MIPI_CSI2_LANE0_N	92	DI		
MIPI_CSI2_LANE0_P	93	DI		
MIPI_CSI2_CLK_N	94	DI		
MIPI_CSI2_CLK_P	95	DI		
MIPI_CSI3_LANE1_N	79	DI	Camera3 MIPI interface	
MIPI_CSI3_LANE1_P	80	DI		
MIPI_CSI3_LANE0_N	81	DI		
MIPI_CSI3_LANE0_P	82	DI		
MIPI_CSI3_CLK_N	83	DI		
MIPI_CSI3_CLK_P	84	DI		
CAM0_RST_N	171	DO	Reset signal for camera 0	
CAM0_PWD_N	172	DO	Power down signal for camera 0	
CAM1_RST_N	173	DO	Reset signal for camera 1	
CAM1_PWD_N	174	DO	Power down signal for camera 1	
CAM2_RST_N	175	DO	Reset signal for camera 2	
CAM2_PWD_N	176	DO	Power down signal for camera 2	
CAM3_RST_N	177	DO	Reset signal for camera 3	

CAM3_PWD_N	178	DO	Power down signal for camera 3	
CAM_I2C_SDA0	180	DIO	camera I2C data 0	
CAM_I2C_SCL0	179	DO	camera I2C clock 0	
CAM_I2C_SDA1	186	DIO	camera I2C data 1	
CAM_I2C_SCL11	185	DO	camera I2C clock 1	
CAM_MCLK0	118	DO	Clock for camera0	
CAM_MCLK1	182	DO	Clock for camera1	
CAM_MCLK2	183	DO	Clock for camera2	
CAM_MCLK3	184	DO	Clock for camera3	
Key interface				
KEY_VOL_UP	43	DI	Volume up	
KEY_VOL_DOWN	44	DI	Volume down	
PWRKEY	8	DI	System power on/off control input, active low.	
Sensor interface				
I2C_SCL	45	DO	I2C clock	
I2C_SDA	46	DIO	I2C data	
ACCEL_INT_N	51	DI	Accelerate sensor interrupt input	
ALSP_INT_N	52	DI	Ambient light sensor interrupt	
MAG_INT_N	53	DI	Magnetic sensor interrupt input	
GYRO_INT_N	62	DI	Gyrocompass sensor interrupt input	
Audio interface				
HPH_L	21	DO	Earphone left tunnel input	
HPH_REF	22	DI	Earphone reference ground	
HPH_R	23	DO	Earphone right tunnel input	
HS_DET	24	DI	Earphone insert detection	
RF interface				
ANT4	11	AIO	5G NR(n79) main antenna	
ANT7	18	AIO	5G NR(n79) main antenna	
ANT3	29	AI	5G NR(n79) MIMO antenna	
ANT9	32	AI	5G NR(n79) MIMO antenna	
ANT5	41	AIO	5G NR(n41)&4G LTE main antenna	
ANT2	49	AIO	5G NR(n41) main antenna&4G LTE diversity antenna	
ANT0	38	AI	5G NR(n41) MIMO antenna	
ANT1	35	AI	5G NR(n41) MIMO antenna	
ANT10	55	AI	GNSS antenna	
ANT_WI-FI0	2	AIO	WI-FI MIMO antenna 0	
ANT_WI-FI1	5	AIO	WI-FI MIMO antenna 1	

ANT_WI-FI02AI/OWI-FI MIMO antenna 0ANT_WI-FI15AI/OWI-FI MIMO antenna 1**UART interface**				
UART1_RX	64	DI	Receive Data 1	
UART1_TX	65	DO	Transmit Data 1	
UART1_RTS	66	DO	Request to send 1	
UART1_CTS	67	DI	Clear to Send 1	
UART2_RX	14	DO	Receive Data 2	
UART2_TX	15	DI	Transmit Data 2	
GPIO				
GPIO	47	DIO	GPIO	
GPIO	187	DIO	GPIO	
Other interface				
FORCED_USB_BOOT	7	DI	Module will be forced into USB download mode by connect this pin to VREG_L5_1P8 during power up.	
PWM	26	DO	Backlight PWM control signal	
ADC0	68	DI	Analog-digital converter input 0	
ADC1	69	DI	Analog-digital converter input 1	

8.4 5G S-Module All-in-one Type-M

8.4.1 Diagram

The 5G S-Module All-in-one block diagram is shown as following:

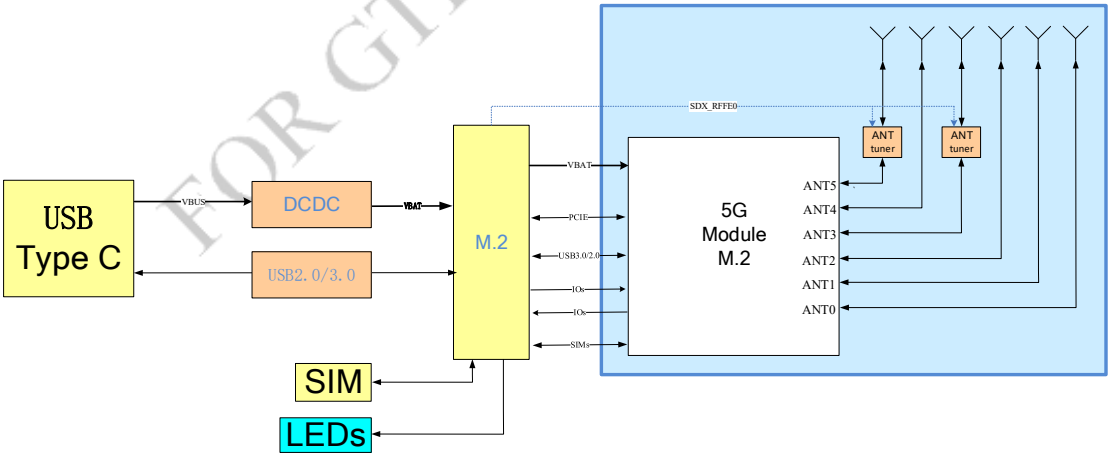


Figure 8-10 5G S-Module All-in-one Type-M Diagram

The All-in-one module Type-M provides terminal the access to cellular network though USB 3.1, which can simplify the design significantly.

The function includes:

- ✓ USB 3.1 data and power supply
- ✓ 5G connectivity

- ✓ SIM socket
- ✓ GNSS Integrated
- ✓ Status indicator
- ✓ External Antenna sockets

8.4.2 PCB Layout

The 5G S-Module All-in-one pcb layout top view.

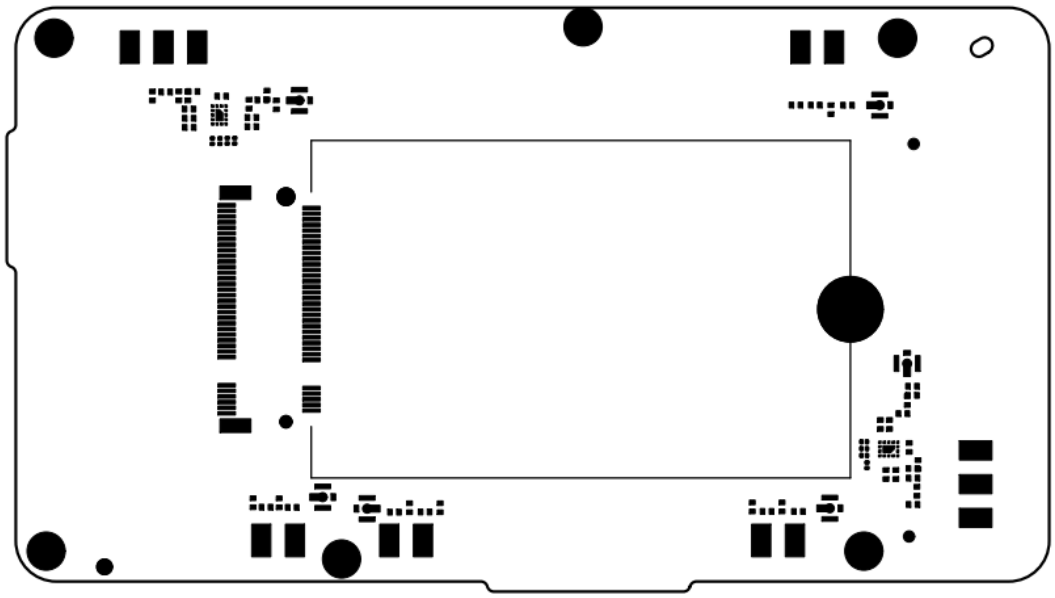


Figure 8-11 5G S-Module All-in-one Type-M Pin Layout top view

The 5G S-Module All-in-one pcb layout BOT view.

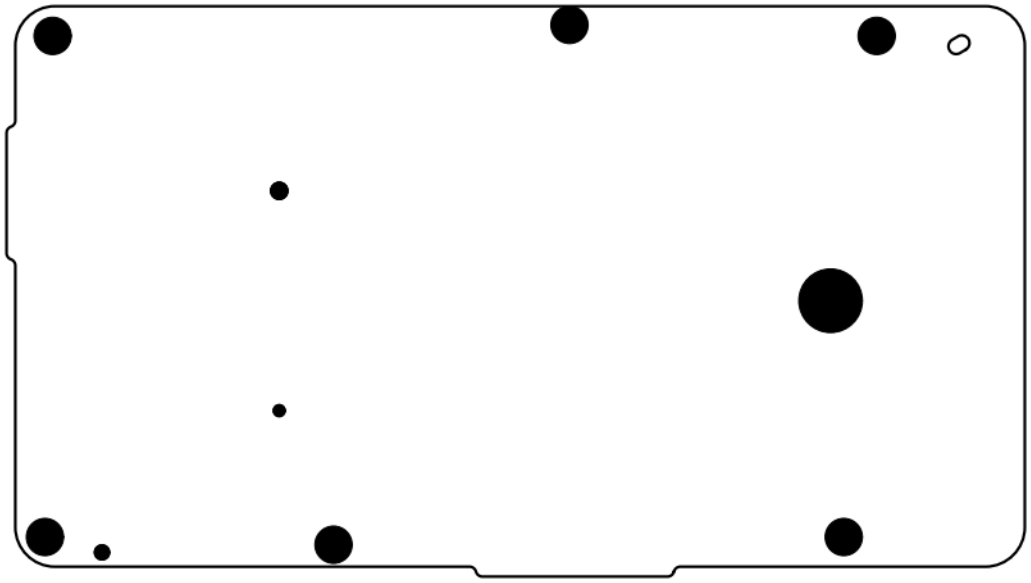


Figure 8-12 5G S-Module All-in-one Type-M Pin Layout BOT view

8.4.3 PCB Size

The 5G S-Module All-in-one pcb size view.

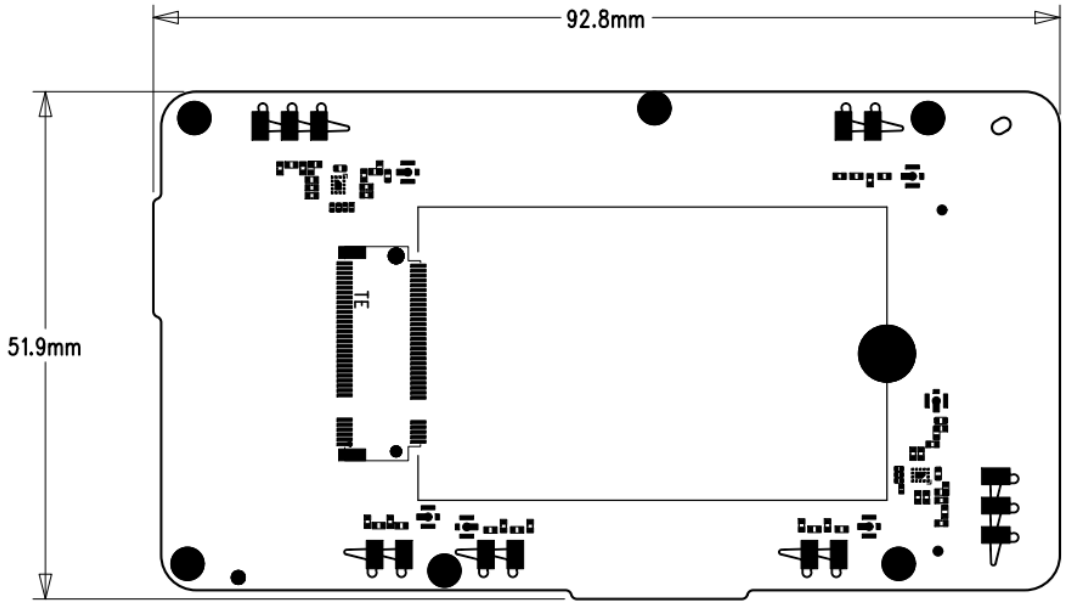


Figure 8-13 5G S-Module All-in-one Type-M PCB Size

8.4.4 Pin Definition

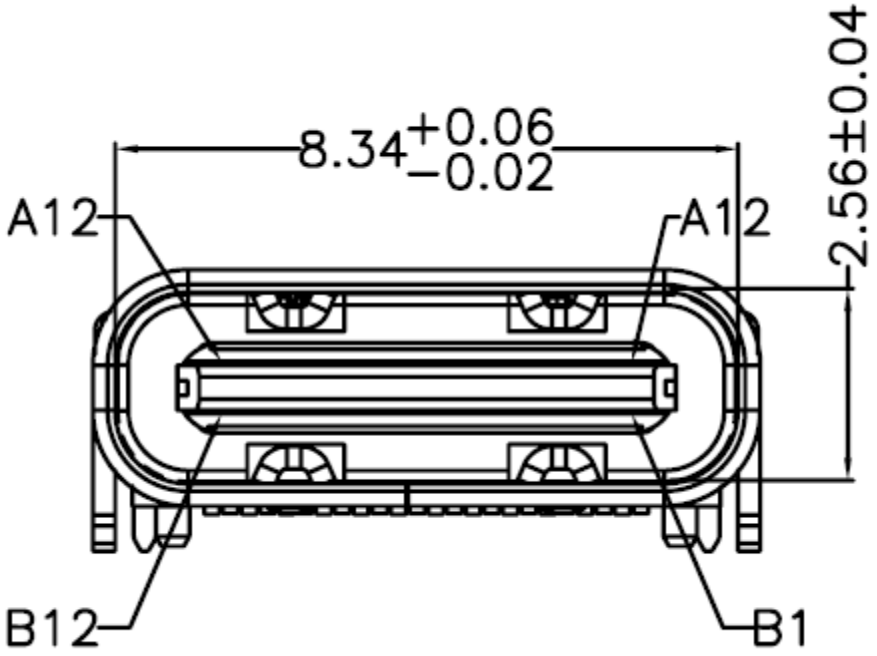


Figure 8-14 5G S-Module All-in-one Type-M USB Type-C Size

USB Type-C Receptacle Interface (Front View).

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1−	VBUS	CC1	D+	D−	SBU1	VBUS	RX2−	RX2+	GND
GND	RX1+	RX1−	VBUS	SBU2	D−	D+	CC2	VBUS	TX2−	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

USB Full-Featured Type-C Plug Interface (Front View)

A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
GND	RX2+	RX2−	VBUS	SBU1	D−	D+	CC	VBUS	TX1−	TX1+	GND
GND	TX2+	TX2−	VBUS	VCONN			SBU2	VBUS	RX1−	RX1+	GND
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12

8.5 5G S-Module All-in-one Type-L

8.5.1 Diagram

5G S-Module All-in-one Type-L Block Diagram is shown as bellowing:

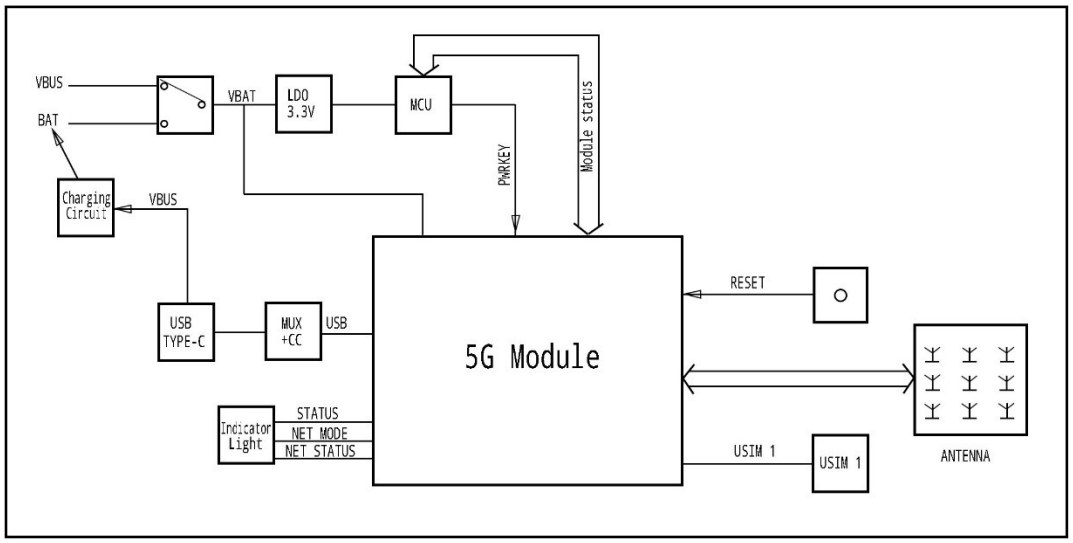


Figure 8-15 5G S-Module All-in-one Type-L Diagram

The All-in-one module Type-L provides terminal the access to cellular network though USB 3.1, which can simplify the design significantly.

The function includes:

- ✓ USB 3.1 data and power supply
- ✓ 5G connectivity
- ✓ SIM socket
- ✓ GNSS Integrated
- ✓ Status indicator
- ✓ External Antenna sockets

8.5.2 PCB Layout

5G S-Module All-in-one Type-L PCB Layout Top View.

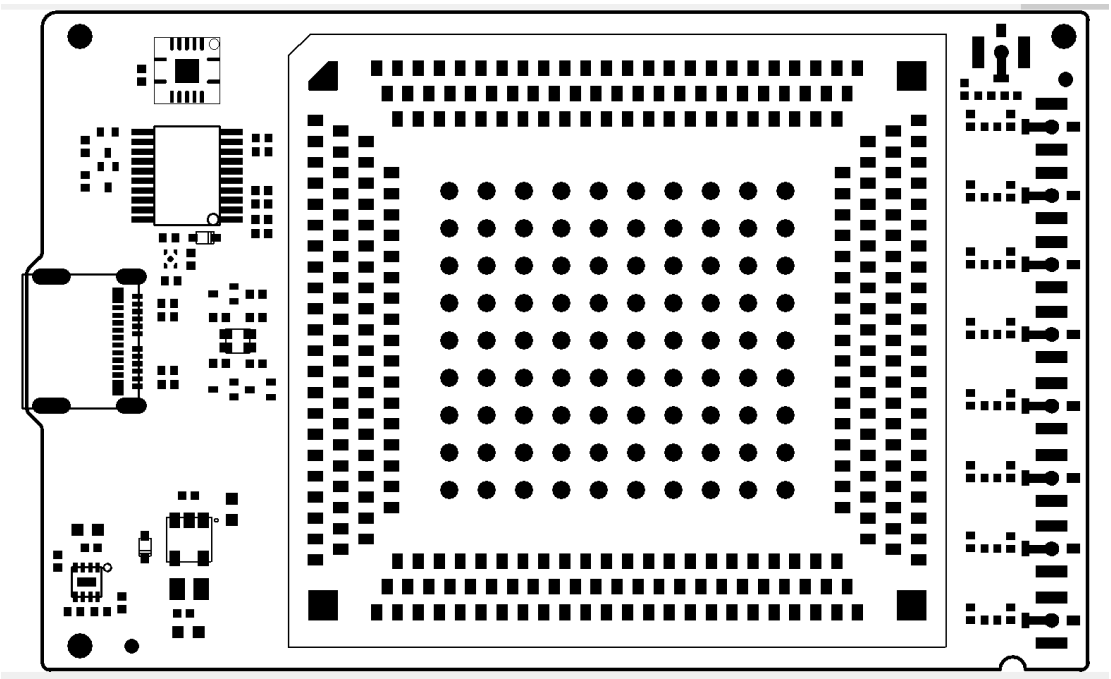


Figure 8-16 5G S-Module All-in-one Type-L Pin Layout top view

5G S-Module All-in-one Type-L PCB Layout Bottom View.

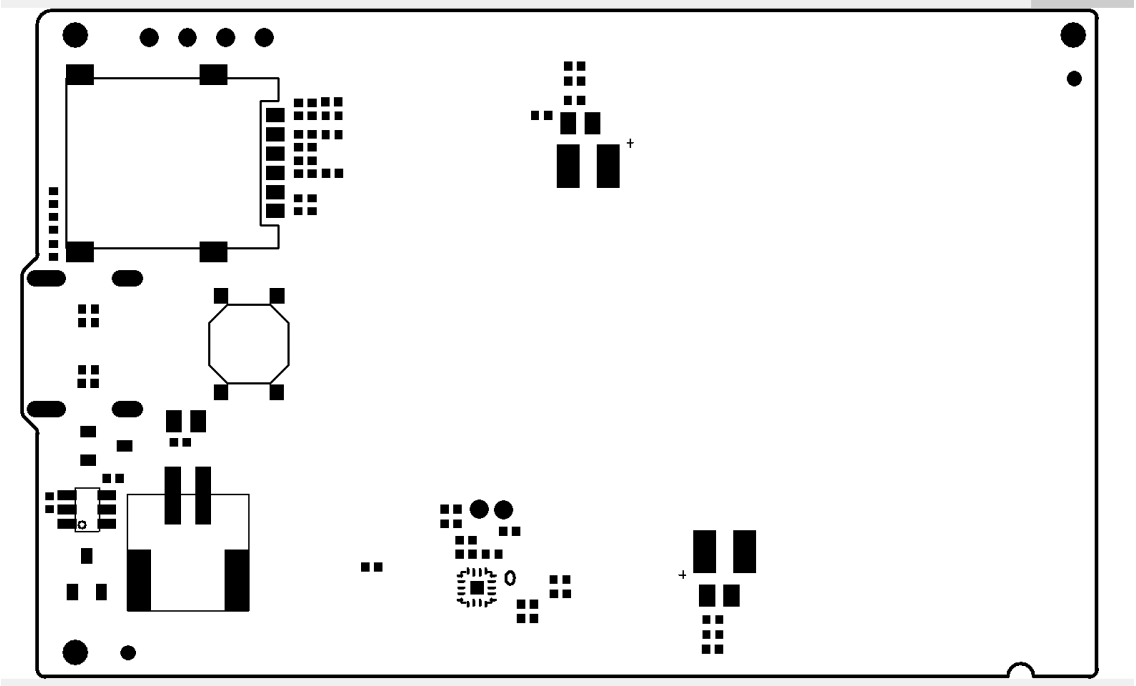


Figure 8-17 5G S-Module All-in-one Type-L Pin Layout BOT view

8.5.3 PCB Size

5G S-Module All-in-one Type-L PCB Size View.

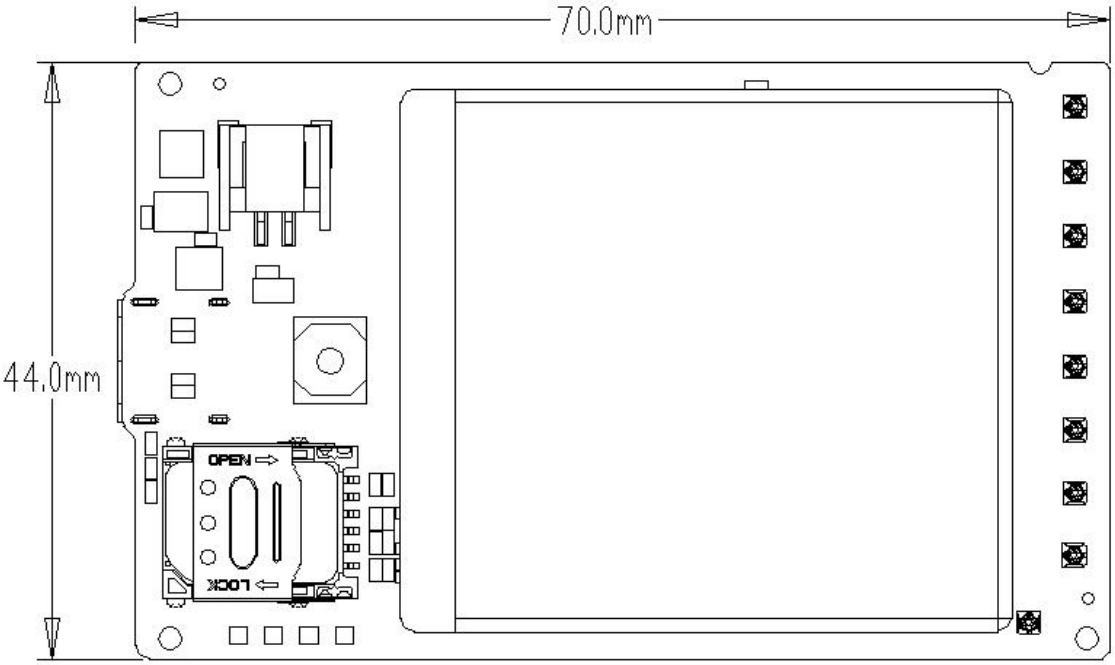


Figure 8-18 5G S-Module All-in-one Type-L PCB Size

8.5.4 Pin Definition

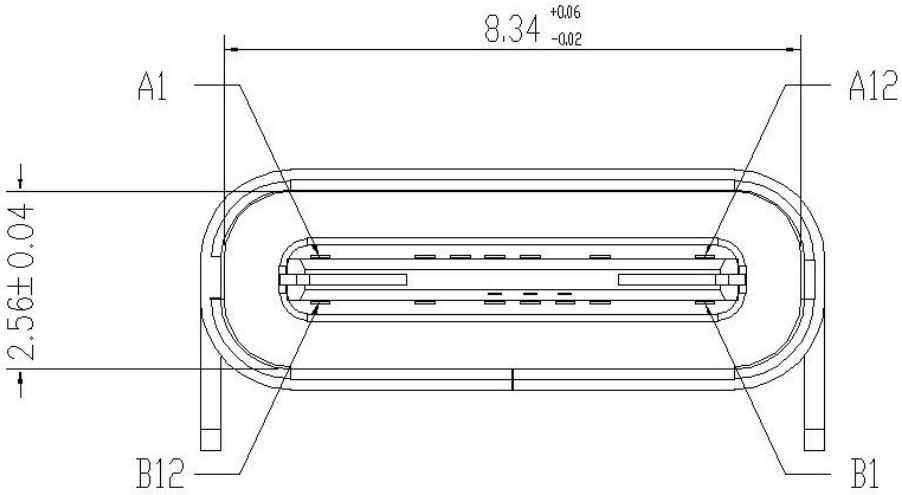


Figure 8-19 5G S-Module All-in-one Type-L USB Type-C Size

USB Type-C Receptacle Interface (Front View)

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1−	VBUS	CC1	D+	D−	SBU1	VBUS	RX2−	RX2+	GND
GND	RX1+	RX1−	VBUS	SBU2	D−	D+	CC2	VBUS	TX2−	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

USB Full-Featured Type-C Plug Interface (Front View)

A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
GND	RX2+	RX2−	VBUS	SBU1	D−	D+	CC	VBUS	TX1−	TX1+	GND
GND	TX2+	TX2−	VBUS	VCONN			SBU2	VBUS	RX1−	RX1+	GND
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12

9 The Electrical Interface Technical Requirements on 5G S-Module

This chapter introduces the main electrical interface (pin definition) of the 5G S-Module, which includes the power interface, control and status interface, RF interface, SIM interface, DATA IO interface, analog interface and audio interface, etc.

9.1 Power Supply Interface

9.1.1 Power Supply

The power pins supply power to RF and baseband circuits.

For VBAT pads the peak current could rises to 2A in some condition and may cause voltage drop, which due to GSM/GPRS emission burst (every 4.615ms). Therefore, the power supply for these pads must be able to provide sufficient current up to 3A in order to avoid the voltage drop to be more than 300mV.

The following figure shows the VBAT voltage ripple wave at the maximum power transmit phase.

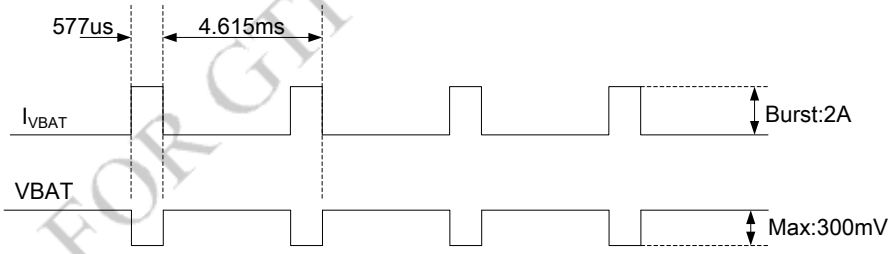


Figure 9-1 VBAT Voltage Drop during Burst Emission (GSM/GPRS)

Table 9-1 VBAT pins electronic characteristic

Symbol	Description	Min.	Typ.	Max.	Unit
VBAT	Module power voltage	3.3	3.8	4.3	V
$I_{VBAT(peak)}$	Module power peak current in normal mode.	-	3	-	A
$I_{VBAT(power-off)}$	Module power current in power off mode.	-	-65	-	uA

9.1.2 Power Supply Design Guide

Make sure that the voltage on the VBAT pins will never drop below 3.4V, even during a transmit burst, when current may rise up to 3A. If the voltage drops below 3.4V, the RF performance may be affected.

Note: If the power supply for VBAT pins can support more than 3A, using a total of more than 300uF capacitors is recommended, or else users must use a total of 1000uF capacitors typically, in order to avoid the voltage drop to be more than 300mV.

Some multi-layer ceramic chip (MLCC) capacitors (0.1/1uF) with low ESR in high frequency band can be used for EMC.

These capacitors should be put as close as possible to VBAT pads. Also, users should keep VBAT trace on circuit board wider than 3 mm to minimize PCB trace impedance. The following figure shows the recommended circuit.

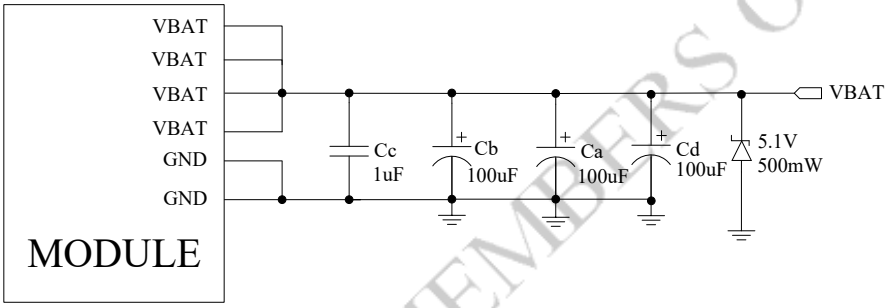


Figure 9-2 Power Supply Application Circuit

Note: The test condition: The voltage of power supply for VBAT is 3.9V, Ca, Cb and Cd were 100 μF tantalum capacitors (ESR=0.7Ω).

In addition, in order to implement over voltage protection, it is suggested to use a Zener diode with 5.1V reverse voltage and more than 500mW power dissipation.

Table 9-2 Recommended Zener Diode List

No.	Manufacturer	Part Number	Power dissipation	Package
1	On semi	MMSZ5231BT1G	500mW	SOD123
2	Prisemi	PZ3D4V2H	500mW	SOD323
3	Vishay	MMSZ4689-V	500mW	SOD123
4	Crownpo	CDZ55C5V1SM	500mW	0805

9.1.3 Recommended Power Supply Circuit

It is recommended that a switching mode power supply or a linear regulator power supply is used. It is important to make sure that all the components used in the power supply circuit can resist the current, which could be more than 3A.

The following figure shows the linear regulator reference circuit with 5V input and 3.8V output.

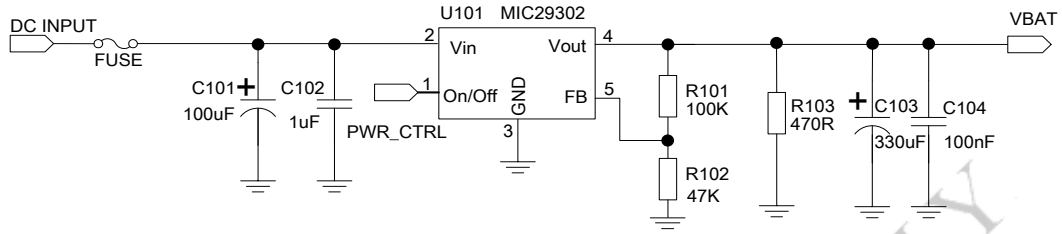


Figure 9-3 Linear Regulator Reference Circuit

If there is a high dropout between input and VBAT, or the efficiency is extremely important, then a switching mode power supply will be preferable. The following figure shows the switching mode power supply reference circuit with 12V input and 3.8V output.

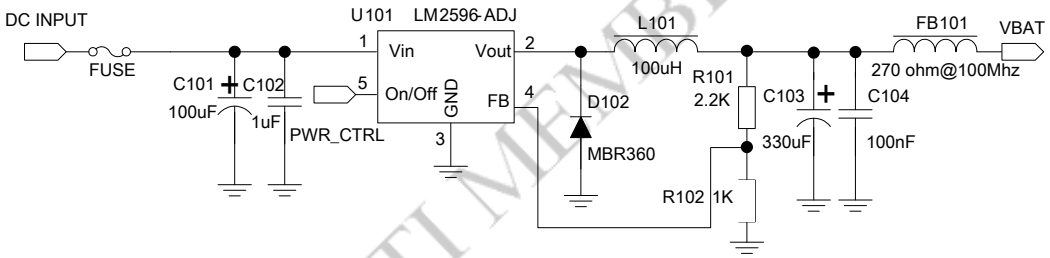


Figure 9-4 Switching Mode Power Supply Reference Circuit

Note: The Switching Mode power supply solution for VBAT must be chosen carefully against Electro Magnetic Interference and ripple current from depraving RF performance.

9.2 Module Control and Status Interface

9.2.1 Power On

Module can be powered on by pulling the PWRKEY pin down to ground.

The PWRKEY pin has been pulled up with a diode to 1.8V internally, so it does not need to be pulled up externally. It is strongly recommended to put a 100nF capacitor, an ESD protection diode, close to the PWRKEY pin as it would strongly enhance the ESD performance of PWRKEY pin. Please refer to the following figure for the recommended reference circuit.

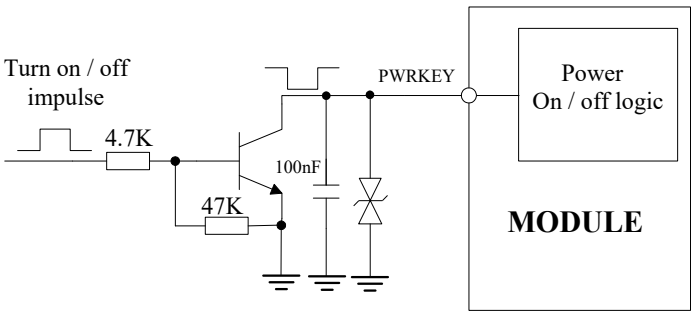


Figure 9-5 Reference Power On/Off Circuit

Note: Module could be automatically power on by connecting PWRKEY pin to ground via 0R resistor directly.

The power-on scenarios are illustrated in the following figure.

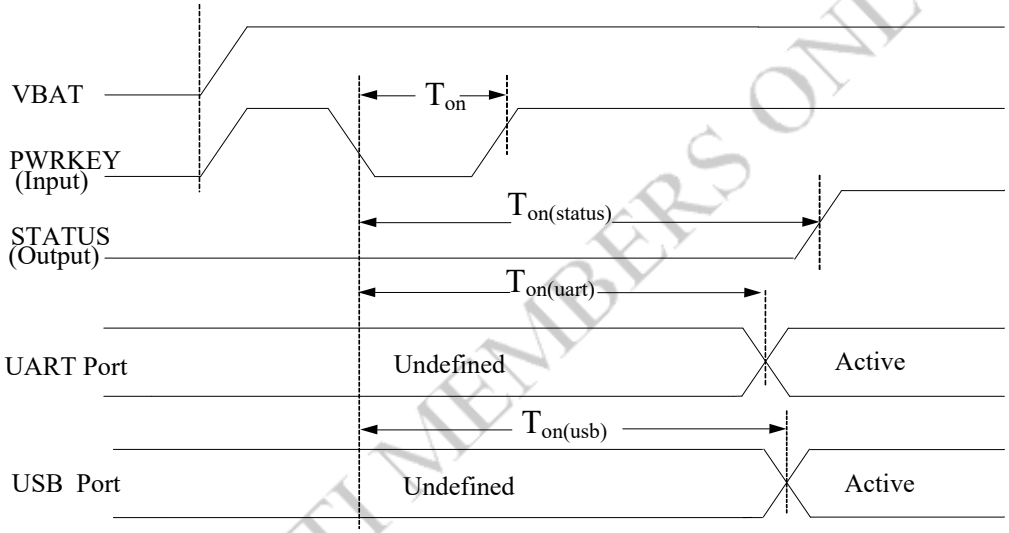


Figure 9-6 Power On Timing Sequence

9.2.2 Power Off

Users could use the PWRKEY to power off MODULE.

These procedures will make MODULE disconnect from the network and allow the software to enter a safe state, and save data before MODULE be powered off completely.

The power off scenario by pulling down the PWRKEY pin is illustrated in the following figure.

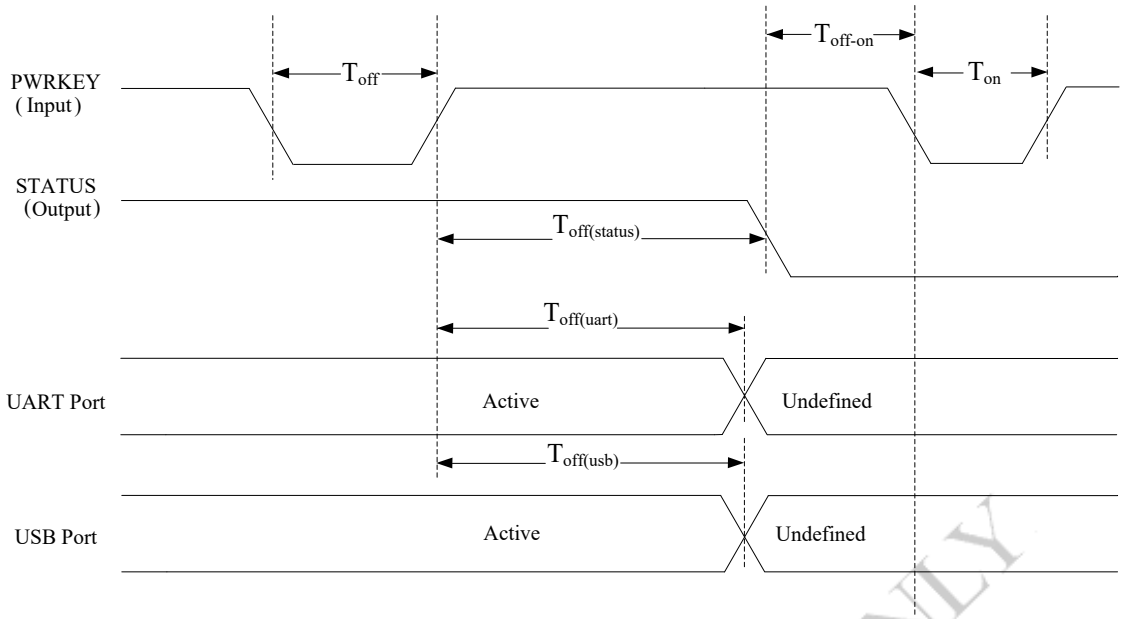


Figure 9-7 Power off timing sequence

9.2.3 Reset Function

Module can be reset by pulling the RESET_N pin down to ground.

Note: This function is only used as an emergency reset.

The RESET_N pin has been pulled up internally, so it does not need to be pulled up externally. It is strongly recommended to put a 100pF capacitor and an ESD protection diode close to the RESET_N pin. Please refer to the following figure for the recommended reference circuit.

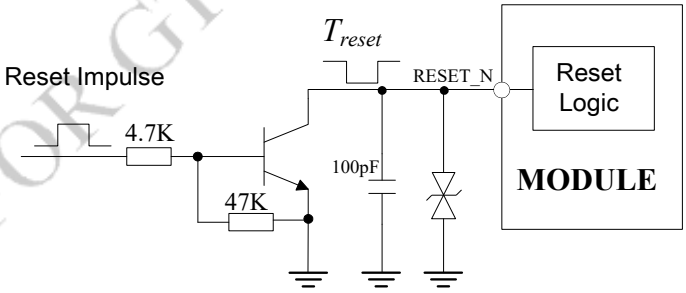


Figure 9-8 Reference Reset Circuit

9.3 RF Interface

9.3.1 GSM /UMTS/LTE/5G sub-6GHz Antenna Design Guide

Users should connect antennas to MODULE's antenna pads through micro-strip line or other

types of RF trace and the trace impedance must be controlled in 50Ω. We recommend that the total insertion loss between the antenna pads and antennas should meet the following requirements:

Table 9-3 Traceloss

Frequency	Loss
700MHz-960MHz	<0.5dB
1710MHz-2170MHz	<0.9dB
2300MHz-2650MHz	<1.2dB
3300MHz-5000MHz	<2dB

For there are many antennas in the system, the isolation from any antenna should be noticed, the minimum requirement is showing below:

1. The isolation from 4G main antenna to the 4G DRX antenna should be more than 20dB which has same band.
2. The isolation from 5G NR main antenna to the 5G NR DRX antenna should be more than 20dB which has same band.
3. The isolation from 4G main antenna to the 5G NR main antenna should be more than 10dB which has different band.
4. The isolation from 4G main antenna to the 5G NR DRX antenna should be more than 10dB.
5. The isolation from 4G main antenna to the GPS antenna should be more than 40dB which has BAND13 and 30dB if not.
6. The isolation from WI-FI antenna to the 4G DRX and main antenna should be more than 30dB which has band7/40 and 20dB if not.
7. The isolation from WI-FI antenna to the 5G NR DRX and main antenna should be more than 20dB

To facilitate the antenna tuning and certification test, a RF connector and an antenna matching circuit should be added. The following figure is the recommended circuit.

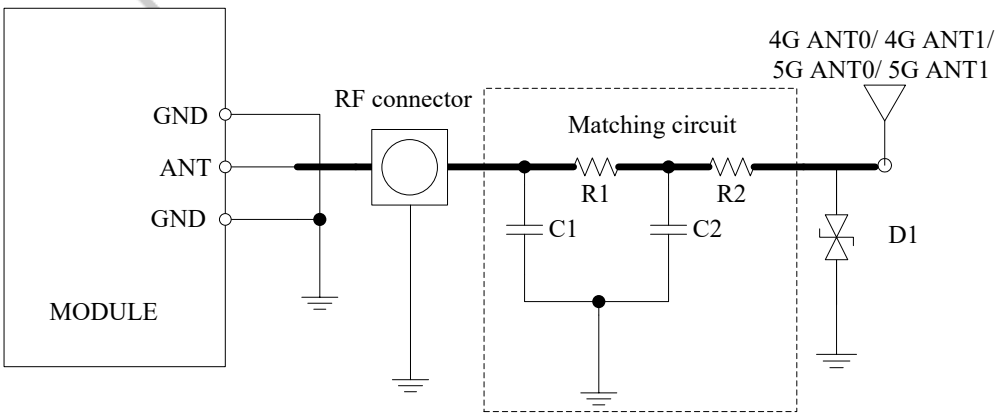


Figure 9-9 Antenna Matching Circuit (ANT_MAIN)

In above figure, the components R1,C1,C2 and R2 are used for antenna matching, the values of components can only be achieved after the antenna tuning and usually provided by antenna vendor. By default, the R1, R2 are 0 Ω resistors, and the C1, C2 are reserved for tuning. The component D1 is a TVS for ESD protection, and it is optional for users according to application environment.

The RF test connector is used for the conducted RF performance test, and should be placed as close as to the MODULE's ANT_MAIN pin. The traces impedance between MODULE and antenna must be controlled in 50 Ω.

Table 9-4 Recommended TVS

Package	Part Number	Vender
0201	LXES03AAA1-154	Murata
0402	LXES15AAA1-153	Murata

9.3.2 GNSS Application Guide

MODULE merges GNSS (GPS/GLONASS/BD) satellite and network information to provide a high-availability solution that offers industry-leading accuracy and performance. This solution performs well, even in very challenging environmental conditions where conventional GNSS receivers fail, and provides a platform to enable wireless operators to address both location-based services and emergency mandates.

Users can place an active antenna or a passive antenna to MODULE.

If using a passive antenna, an external LNA is necessary to get better performance. The following Figure 9-10 is the reference circuit.

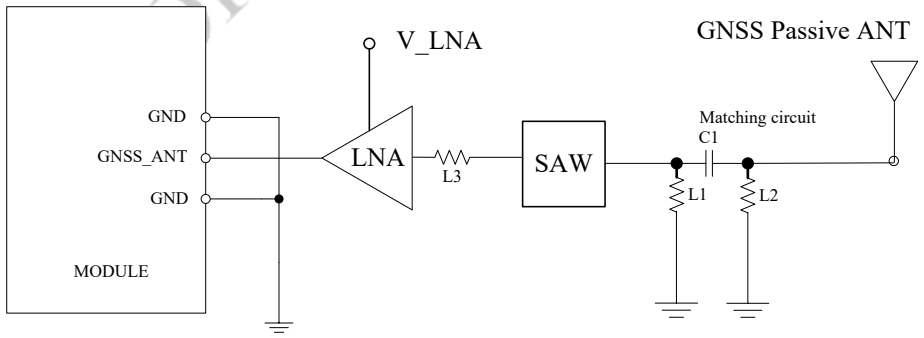


Figure 9-10 Passive Antenna Circuit (Default)

If using an active antenna, then external VDD power supplied to antenna, is not required because it can be given from MODULE.

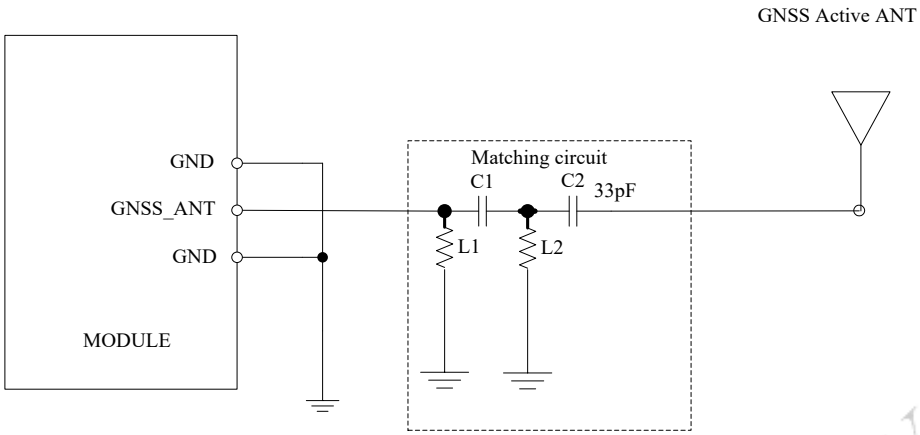


Figure 9-11 Active antenna circuit

In above figures, the components C1, L1 and L2 are used for antenna matching. Usually, the values of the components can only be achieved after antenna tuning and usually provided by antenna vendor. C2 is used for DC blocking. L3 is the matching component of the external LNA, and the value of L3 is determined by the LNA characteristic and PCB layout.

Both VDD of active antenna and V_LNA need power supplies which can be supplied by MODULE. LDO/DCDC is recommended to get lower current consuming by shutting down active antennas and LNA when GNSS is not working.

9.3.3 Wi-Fi/BT Application Guide

Users should connect antennas to MODULE's antenna pads through micro-strip line or other types of RF trace and the trace impedance must be controlled in 50 Ω.

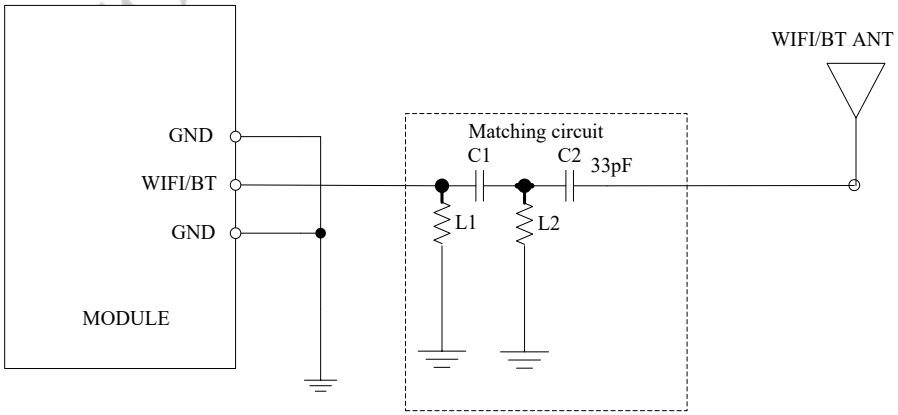


Figure 9-12 Active Antenna Circuit

In above figures, the components C1, L1 and L2 are used for antenna matching. Usually, the values of the components can only be achieved after antenna tuning and usually provided by

antenna vendor.C2 is used for DC blocking.

9.4 SIM Interface

MODULE supports both 1.8V and 3.0V USIM Cards.

Table 9-5 USIM Electronic Characteristic in 1.8V Mode (USIM_VDD=1.8V)

Symbol	Parameter	Min.	Typ.	Max.	Unit
USIM_VDD	LDO power output voltage	1.75	1.8	1.95	V
V_{IH}	High-level input voltage	0.65*USIM_VDD	-	USIM_VDD +0.3	V
V_{IL}	Low-level input voltage	-0.3	0	0.35*USIM_VDD	V
V_{OH}	High-level output voltage	USIM_VDD -0.45	-	USIM_VDD	V
V_{OL}	Low-level output voltage	0	0	0.45	V

Table 9-6 USIM electronic characteristic 3.0V mode (USIM_VDD=2.95V)

Symbol	Parameter	Min.	Typ.	Max.	Unit
USIM_VDD	LDO power output voltage	2.75	2.95	3.05	V
V_{IH}	High-level input voltage	0.65*USIM_VDD	-	USIM_VDD +0.3	V
V_{IL}	Low-level input voltage	-0.3	0	0.25*USIM_VDD	V
V_{OH}	High-level output voltage	USIM_VDD -0.45	-	USIM_VDD	V
V_{OL}	Low-level output voltage	0	0	0.45	V

9.4.1 USIM Application Guide

It is recommended to use an ESD protection component such as ESDA6V1-5W6 produced by ST or SMF12C produced by ON SEMI. Note that the USIM peripheral circuit should be close to the USIM card socket. The following figure shows the 6-pin SIM card holder reference circuit.

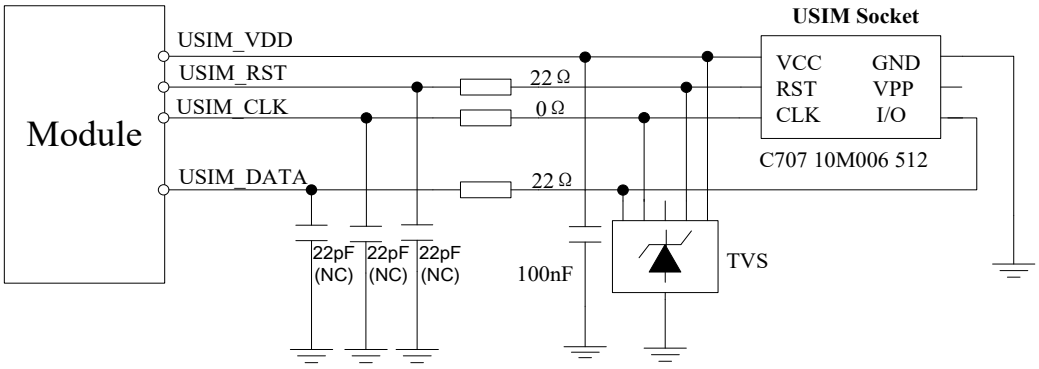


Figure 9-13 USIM Interface Reference Circuit

The USIM_DET pin is used for detection of the USIM card hot plug in. User can select the 8-pin USIM card holder to implement USIM card detection function.

The following figure shows the 8-pin SIM card holder reference circuit.

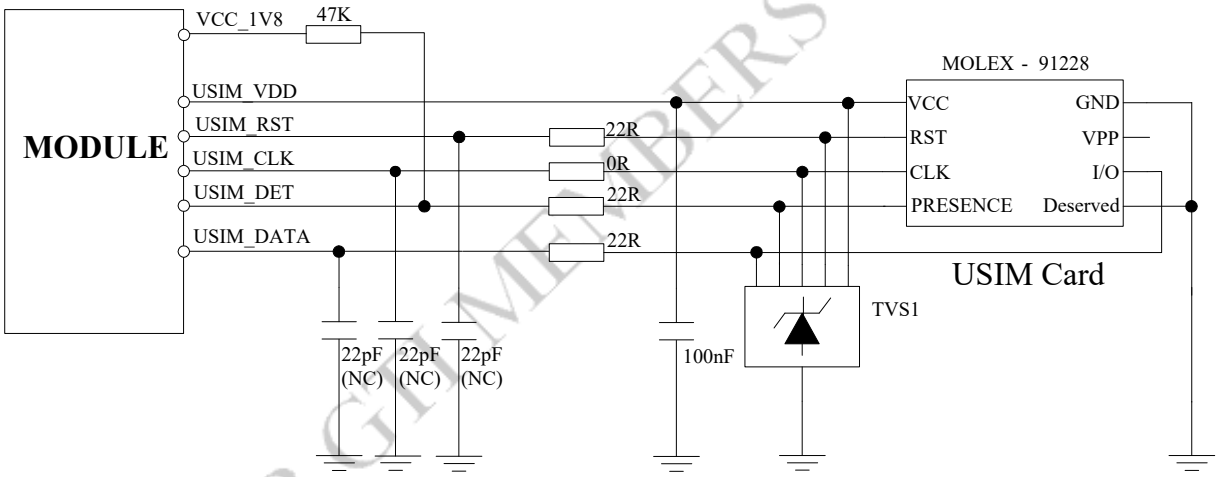


Figure 9-14 USIM Interface Reference Circuit with USIM_DET

If the USIM card detection function is not used, user can keep the USIM_DET pin open.

SIM card circuit is susceptible, and the interference may cause the SIM card failures or some other situations, so it is strongly recommended to follow these guidelines while designing:

- Make sure that the SIM card holder should be far away from the antenna in PCB layout.
- SIM traces should keep away from RF transmission lines, VBAT and high-speed signal transmission lines.
- The traces should be as short as possible.
- Keep SIM holder's GND connect to main ground directly.
- Shield the SIM card signal by ground.

- Recommended to place a 0.1~1uF capacitor on USIM_VDD line and keep close to the holder.
- The rise/fall time of USIM_CLK should not be more than 40ns.
- Add some TVS diodes, and the parasitic capacitance should not exceed 60pF.

9.5 Data I/O Interface

9.5.1 UART Interface

MODULE may support 2-wire or 4-wire or 8-wire UART interface.
2-wire UART interface: including UART_ RXD and UART_ TXD interface.
4-wire UART interface: including UART_ RTS、UART_ CTS、UART_RXD and UART_TXD interface.
8-wire UART interface: including all interfaces in the following table.

Interface Type	Interface Name	Interface Description	Interface Characteristics
8-wire UART interface	UART_RXD	Data receive	I
	UART_TXD	Data sending	O
	UART_RTS	Data sending request	I
	UART_CTS	Clearing to send	O
	UART_DSR	Data ready on the wireless module	O
	UART_DCD	Data carrier detection	O
	UART_RI	Ringing indication	O
	UART_DTR	Data terminal ready	I

The MODULE UART interface shall support 8 bit data transmission, and may support 5 / 6 / 7 bit data transmission.
The MODULE UART interface shall support rates between 9600 and 115200, and may support adaptive baud rate.

9.5.2 The MODULE shall support 4-wire UART interface, and may support 8-wire UART interface.I2C Interface

MODULE provides I2C interface to control the external device. Its operation voltage is 1.8V.

The following figure shows the I2C bus reference design.

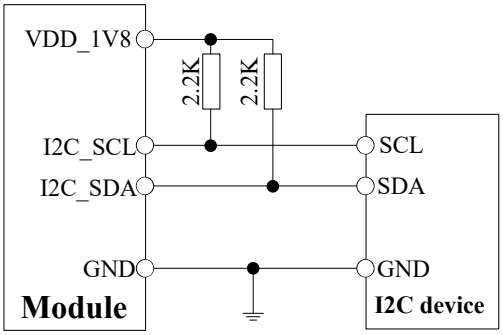


Figure 9-5 I2C Reference Circuit

Note：SDA and SCL have no pull-up resistors in MODULE. Therefore, 2 external pull up resistors are necessary in application circuit.
The I3C protocol will be supported in the future.

9.5.3 SPI Interface

Module provides the SPI interface as master only. It provides a duplex, synchronous, serial communication link with peripheral devices. Its operation voltage is 1.8V, with clock rates up to 50 MHz

The SPI interface could also be configured as UART, I2C or GPIOs, which could refer to the Table 10 below.

Table 9-7 SPI Configuration

Default mode	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
SPI_MOSI	TXD	TXD	TXD	GPIO	GPIO
SPI_MISO	RXD	RXD	RXD	GPIO	GPIO
SPI_CS	CTS	I2C_SDA	GPIO	I2C_SDA	GPIO
SPI_CLK	RTS	I2C_SCL	GPIO	I2C_SCL	GPIO

9.6 Analog Interface

9.6.1 ADC

MODULE has two dedicated ADC pins named ADC0 and ADC1.They are available for digitizing analog signals such as battery voltage and so on. These electronic specifications are shown in the

following table.

Table 9-8 ADC0 and ADC1 Electronic Characteristics

Characteristics	Min.	Typ.	Max.	Unit
Resolution	–	16	–	Bits
Conversion time	–	442	–	us
Input Range	0.1		1.7	V
Input serial resistance	1	–	–	MΩ

9.7 Audio Interface

9.7.1 I2S Interface

MODULE provides an I2S interface for external codec, which comply with the requirements in the Phillips I2S Bus Specifications.

Table 9-9 I2S Format

Characteristics	Specification
LineInterfaceFormat	Linear(Fixed)
Datalength	16bits(Fixed)
I2S Clock/SyncSource	Master Mode(Fixed)
I2S ClockRate	1.536 MHz (Default)
I2S MCLK rate	12.288MHz (Default)
DataOrdering	MSB

Note: For more details about I2S AT commands, please refer to [1].

9.7.1.1 I2S timing

MODULE supports 48 KHz I2S sampling rate and 32 bit coding signal (16 bit word length), the timing diagram is showed as following:

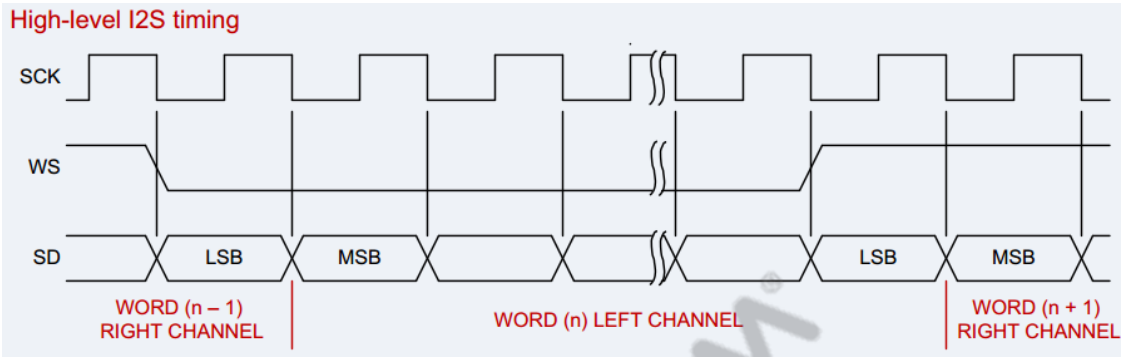


Figure 9-6 I2S Timing

Table 9-10 I2S Timing Parameters

Signal	Parameter	Description	Min.	Typ.	Max.	Unit
I2S_MCLK	Frequency	Frequency	–	12.288	12.288	MHz
	T	Clock period	81.380	81.380	–	ns
	t(HC)	Clock high	0.45T	–	0.55T	ns
	t(LC)	Clock low	0.45T	–	0.55T	ns
I2S_CLK	Frequency	Frequency	8	48	48	KHz
	T	Clock period	20.83	20.83	125	us
	t(HC)	Clock high	0.45T	–	0.55T	ns
	t(LC)	Clock low	0.45T	–	0.55T	ns
I2S_WS	t(sr)	DIN/DOUT and WS input setup time	16.276	–	–	ns
	t(hr)	DIN/DOUT and WS input hold time	0	–	–	ns
	t(dtr)	DIN/DOUT and WS output delay	–	–	65.10	ns
	t(htr)	DIN/DOUT and WS output hold time	0	–	–	ns

9.7.1.2 I2S reference circuit

The following Figure 9-18 shows the external codec reference circuit.

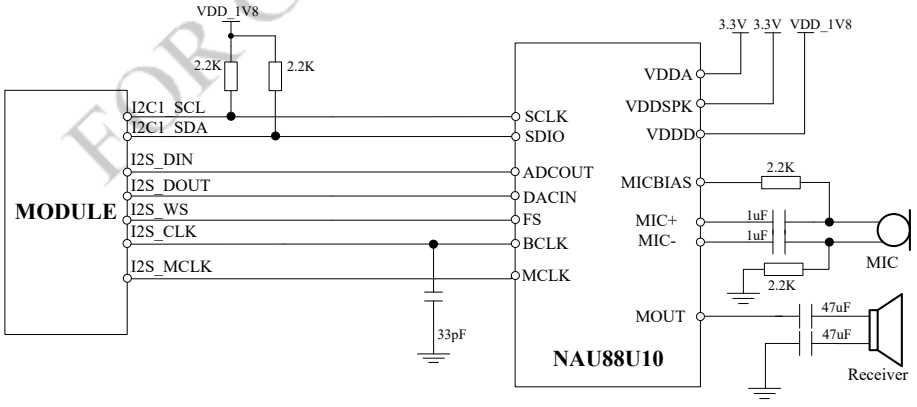


Figure 9-7 Audio codec reference circuit

Module provides one analog input, which could be used for electric microphone. The module also provides one analog output. The output can directly drive 32Ω receiver.

In order to improve audio performance, the following reference circuits are recommended. The audio signals have to be layout according to differential signal layout rules as shown in following Figure 9-18 to Figure 9-21. Amplifier circuit for audio could be used, for example, National Semiconductor Company's LM4890.

9.7.2 Speaker Interface Configuration

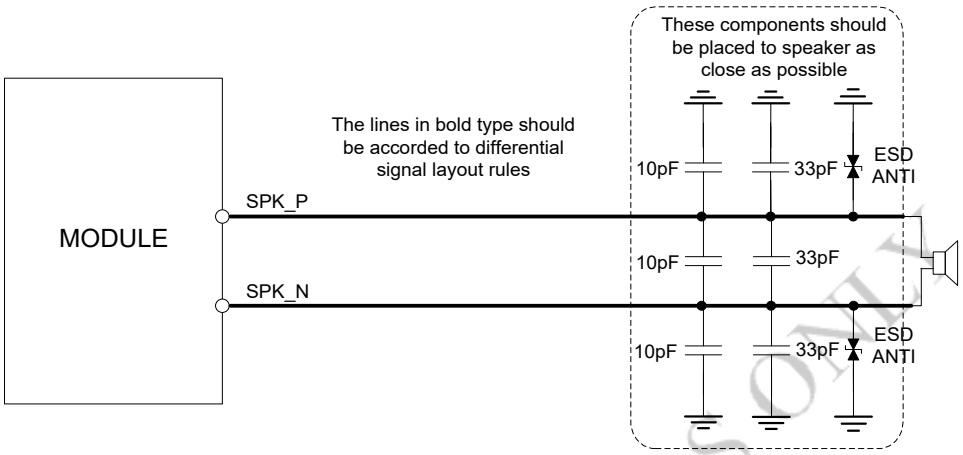


Figure 9-8 Speaker Reference Circuit

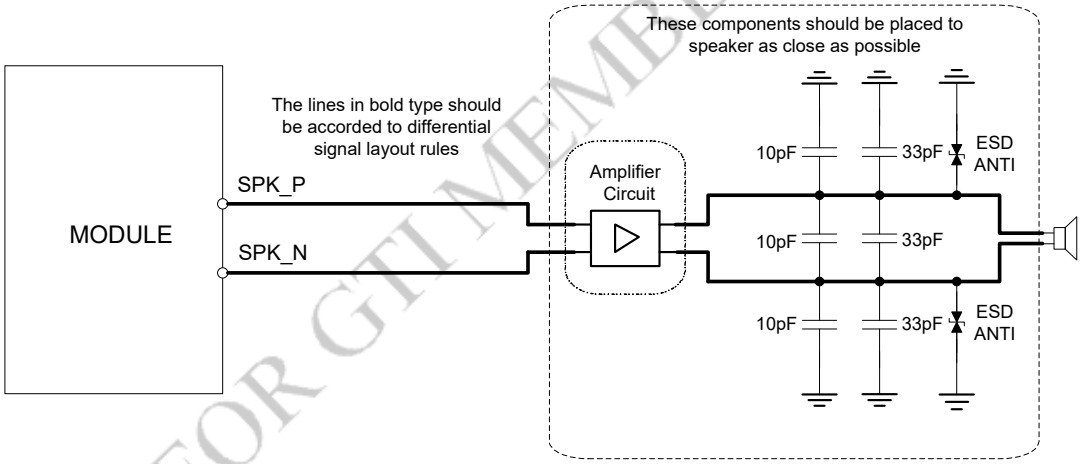


Figure 9-19: Speaker with Amplifier Reference Circuit

9.7.3 Microphone Interfaces Configuration

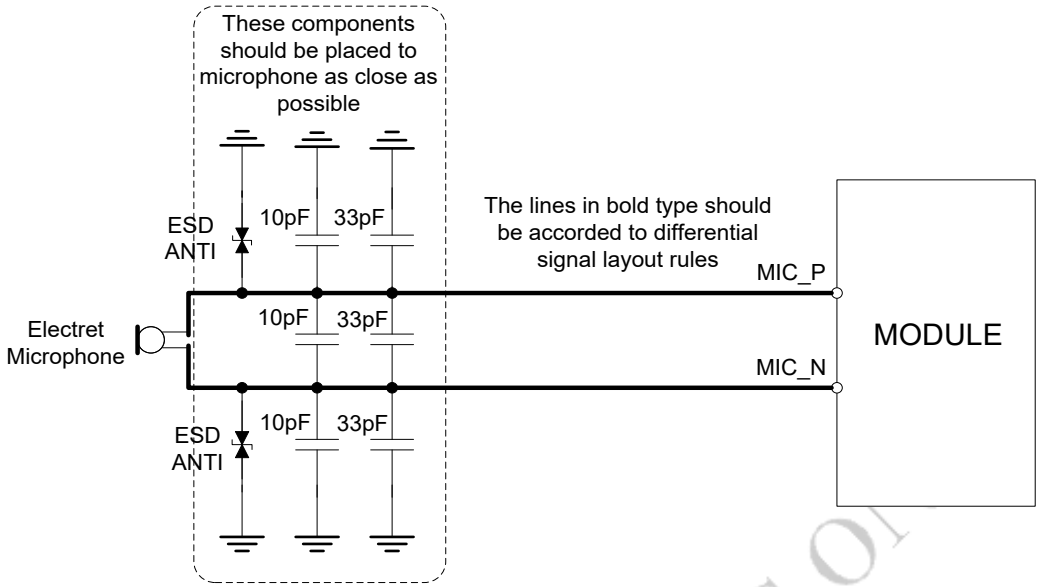


Figure 9-0 Microphone Reference Circuit

9.7.4 Earphone Interface Configuration

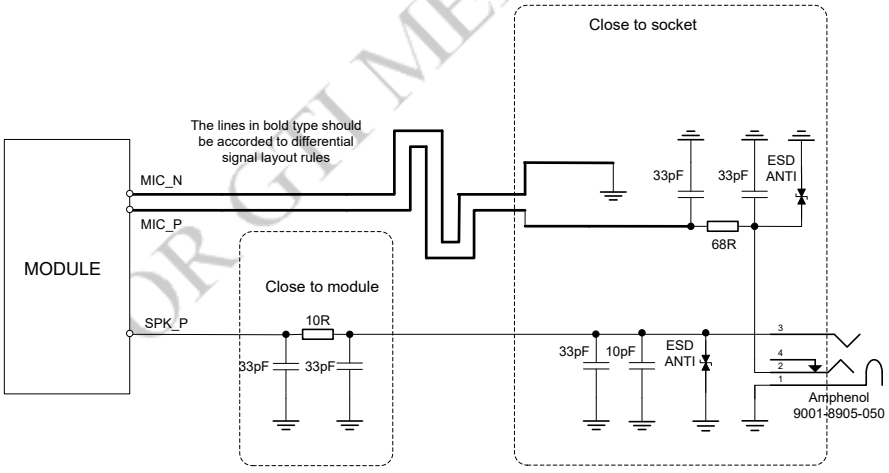


Figure 9-1 Earphone Reference Circuit

10 The Test and Certification of 5G S-Module

When the 5G S-Module is developed, it will undergo certain test and certification before it goes to the market. First we need do lab test and field test, then we will do industry test and regulatory test, and the last step will be the carrier acceptance test.

As for the electrical interface test, further studies will be needed.

10.1 Lab Conformance Test

Lab RF/RRM/SIG conformance test should be done to test the 5G S-Module functions and performance. We should generate the first batch of test cases needed for 5G S-Module.

3GPP Status: RF test case is defined in TS 38.521-1[6], TS 38.521-2[7], TS 38.521-3[8], Performance test is defined in TS 38.521-4[9]. RRM is defined in TS 38.533[13]. Protocol test cases are defined in TS 38.523-1[10], TS 38.523-2[11] with the test module and TTCN implementation in TS 38.523-3[12].

3GPP TS 38.101-1[2], TS 38.101-2[3], TS 38.101-3[4], TS 38.101-4[5] defined sub6G, mmWave, LTE-NR/FR1-FR2 inter-working and performance test requirements. After test method and test procedure implemented, TS38.521 will publish for real test.

An estimate of 37 test cases for RX / TX test will be published in Dec 2018 for TS 38.521 -1/-2, Performance test cases for TS 38.521-4 will be published in summer 2019. RRM test cases will publish in summer 2019.

The lab test cases that should be run against the 5G S-Module are defined in the following 3GPP test specifications.

Table 10-1 3GPP RAN5 5GS Conformance Test Specifications

Test Specification	Description
3GPP TS 38.521-1	5G NR RF conformance test cases, FR1 (sub 6GHz), Standalone
3GPP TS 38.521-2	5G NR RF conformance test cases, FR2 (mmWave), Standalone
3GPP TS 38.521-3	5G NR RF conformance test cases, FR1 + FR2 interworking, Inter-RAT and Non-standalone
3GPP TS 38.521-4	5G NR RF conformance test cases, Performance
3GPP TS 38.523-1	5G NR Protocol conformance test cases
3GPP TS 38.533	5G NR RRM conformance test cases
3GPP TS 34.229-1	5G NR IMS conformance test cases
3GPP TS 37.571-1	5G NR Positioning conformance test cases, RF
3GPP TS 37.571-2	5G NR Positioning conformance test cases, Protocol

Lab testing is usually performed as part of the GCF device certification process, but may also be performed during the R&D phase to ensure that the device is ready to undergo formal GCF testing at an independent test laboratory. The test equipment and test cases used are the same as those that are validated at GCF.

After the lab test and field test are finished, we could start the industry regulatory test such as FCC/PTCRB/IC/GCF/GTI, etc.

GCF Status:

In RAN# 80 Meeting held in June 2018, NSA Option3 EN-DC phase 1 test case was defined. A list of EN-DC golden protocol test cases were selected for initial TTCN implementation and is a shown below and they have been released by ETSI.

Table 10-2 List of Protocol Conformance Golden Test Cases

SIG TC# (38.523-1 [1])	SIG test case (TC) title	RAN5#79 pCR#(s)	UE capability dependency (38.306 [2])
MAC			
7.1.1.2.1	Correct Handling of DL MAC PDU / Assignment / HARQ process	R5-182940, R5-183143	
RLC			
7.1.2.2.4	UM RLC / 12-bit SN / Correct use of sequence numbering	R5-183144, R5-183149	***um-WIthLongSN***
7.1.2.3.4	AM RLC / 18-bit SN / Correct use of sequence numbering	R5-183144, R5-183150, R5-182966	
PDCP			
7.1.3.1.2	Maintenance of PDCP sequence numbers / User plane / 18 bit SN	R5-183145, R5-182945	
RRC			
8.2.2.4.1	PSCell addition, modification and release / SCG DRB / EN-DC	R5-183230	
8.2.2.5.1	PSCell addition, modification and release / Split DRB / EN-DC	R5-183135	
8.2.2.9.1	Bearer Modification / Uplink data path / Split DRB Reconfiguration / EN-DC	R5-183115	
8.2.3.1.1	Measurement configuration control and reporting / Inter-RAT measurements / Event B1 / Measurement of NR cells / EN-DC	R5-183117	
8.2.3.4.1	Measurement configuration control and reporting / Event A1 / Measurement of NR PSCell / EN-DC	R5-183134	
NAS			
10.2.1.2	Dedicated EPS bearer context activation	none	

The next target for TTCN implementation is to have 80% of NSA Option 3 test cases implemented by end of October.

The first delivery of TTCN test cases for SA Option 2 is planned for early December.

In a recent RAN5 NR AH#3 meeting, the plan to develop the NSA and SA test cases in the test specifications have been revised in R5-185691 and is shown below:-

› Overview: Time line - RAN5 5G NR targets

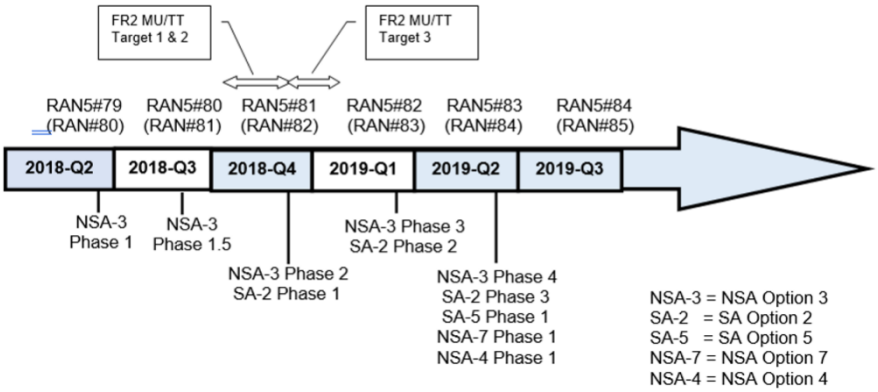


Figure 10-1 The plan to develop the NSA and SA test cases

An additional delivery point has been added to Feb-2019 for SA phase 2 and NSA phase 3. This is an aimed as accelerating the SA test case development.

10.1.1 GCF Testing

The Global Certification Forum (GCF) is responsible for administering a certification program for devices that support 3GPP mobile communication technologies. Many major mobile network operators around the world require devices to be certified according to the current GCF certification requirements.

GCF device certification must be performed by a GCF Recognized Test Organization, using test equipment and test cases that have been validated by an independent test laboratory. The GCF certification requirements are grouped into work items, with the following 5G work item structure being agreed at the CAG#54bis meeting in May 2018:

Table 10-3 GCF New Work Items for 5G Conformance Tests

Umbrella Work Item	Sub Work Items	3GPP Test Specifications
WI-500: 5G RF	WI-500_NR-*nx* WI-500_EUTRA-5GC-*x* WI-500_EN-DC_*x*_*ny* WI-500_NGEN-DC_*x*_*ny*	3GPP TS 38.521-1 3GPP TS 38.521-2 3GPP TS 38.521-3
WI-501: 5G RRM	WI-501_NR-*nx* WI-501_EUTRA-5GC-*x* WI-501_EN-DC_*x*_*ny* WI-501_NGEN-DC_*x*_*ny*	3GPP TS 38.533
WI-502: 5G De-Mod/CSI	WI-502_NR-*nx* WI-502_EUTRA-*5GC-x* WI-502_EN-DC_*x*_*ny* WI-502_NGEN-DC_*x*_*ny*	3GPP TS 38.521-4
WI-503: 5G AS Protocol	WI-503_NR-*nx*	3GPP TS 38.523-1

Umbrella Work Item	Sub Work Items	3GPP Test Specifications
	WI-503_EUTRA-*5GC-x* WI-503_EN-DC_*x_ny* WI-503_NGEN-DC_*x_ny*	
WI-504: 5G NAS Protocol	WI-504_NR-*nx* WI-504_EUTRA-5GC-*x* WI-504_EN-DC_*x_ny* WI-504_NGEN-DC_*x_ny*	3GPP TS 38.523-1
WI-505: IMS Protocol	*N/A – band independent*	3GPP TS 34.229-1
WI-506: 5G Positioning	*N/A – band independent*	3GPP TS 37.579-1

At the CAG#55 meeting in July 2018, sub-work items for WI-500, WI-503 and WI-504 were created for the following bands / band combinations, with further bands due to be added at future CAG meetings:

Table 10-4 List of NR-LTE Band Combinations for 5G Conformance Tests

Band	Number of test cases in sub-work item		
	WI-500-*{band}*	WI-503-*{band}*	WI-504-*{band}*
EN-DC_(n)41A		88	
EN-DC_19A_n77A	21		
EN-DC_19A_n78A	21		
EN-DC_1A_n77A	21		
EN-DC_1A_n78A	21	88	3
EN-DC_25A_n41A		88	
EN-DC_39A_n78A	21	88	3
EN-DC_39A_n79A	21	88	3
EN-DC_3A_n77A	21	88	3
EN-DC_3A_n78A	21	88	3
EN-DC_3A_n79A	21	88	3
EN-DC_41A_n41A		88	
EN-DC_41A_n78A	21	88	3
EN-DC_41A_n79A	21	88	3
EN-DC_5A_n78A	21	88	3
EN-DC_7A_n78A	21	88	3
EN-DC_8A_n78A	21	88	3
EN-DC_8A_n79A	21	88	3
n78	40		
n79	40		

Validation of the above test cases against 5G test platforms is estimated as follows:

- CAG#57 (January 2019) = NSA Opt3 (EN-DC) FR1 (sub-6GHz bands)
- CAG#57 (January 2019) = NSA Opt3 (EN-DC) FR2 (mmWave bands)
- CAG#58 (April 2019) = SA Opt2 (NR) FR1 (sub 6GHz bands)

Full details of the current GCF certification requirements can be found in the GCF Device

Certification Criteria (DCC) database, which is accessible to GCF member companies at https://www.globalcertificationforum.org.

10.1.2 PTCRB Testing

PTCRB have defined their 5G RFT structure as follows:

RFT	Description	Test Cases
501-1	5G RF NR	TBD
501-2	5G RF EUTRA-5GC	TBD
501-3	5G RF EN-DC	5
501-4	5G RF NGEN-DC	TBD
502-1	5G RRM NR	TBD
502-2	5G RRM EUTRA-5GC	TBD
502-3	5G RRM EN-DC	TBD
502-4	5G RRM NGEN-DC	TBD
503-1	5G De-Mod/CSI NR	TBD
503-2	5G De-Mod/CSI EUTRA-5GC	TBD
503-3	5G De-Mod/CSI EN-DC	TBD
503-4	5G De-Mod/CSI NGEN-DC	TBD
504-1	5G RAN Protocol NR	TBD
504-2	5G RAN Protocol EUTRA-5GC	TBD
504-3	5G RAN Protocol EN-DC	75
504-4	5G RAN Protocol NGEN-DC	TBD
505-1	5G NAS Protocol NR	TBD
505-2	5G NAS Protocol EUTRA-5GC	TBD
505-3	5G NAS Protocol EN-DC	3
505-4	5G NAS Protocol NGEN-DC	TBD
506-1	5G IMS Protocol	TBD
507-1	5G Positioning	TBD

Source: outcome from PVG#82 meeting

Following list of bands has been added:

- FR1:
  - n71, n78A
- FR2:
  - n257A, n260?, n261A
- DC:
  - DC_5A_n78A, DC_7A_n78A, DC_5A-7A_n78A, DC_7A-7A_n78A, DC_7C_n78A, DC_2A_n257A, DC_5A_n257A, DC_7A_n257A, DC_2A-5A_n257A, DC_2A-66A_n257A, DC_5A-66A_n257A, DC_5A-7A_n257A, DC_7A-7A_n257A, DC_66A-66A_n257A, DC_5A-7A-7A_n257A
  - DC_2A-66A_n261A-n261A, DC_2A-66A_n261A, DC_66A_n261A-n261A, DC_2A_n261A-n261A, DC_2A_n261A,DC_66A_n261A
  - DC_2A-66A_n260A-n260A, DC_2A-66A_n260A, DC_66A_n260A-n260A, DC_2A_n260A-n260A, DC_2A_n260A, DC_66A_n260A
  - DC_2A-66A_(n)71B, DC_2A-66A_n71A, DC_2A_(n)71B, DC_66A_(n)71B, DC_(n)71B, DC_66A_n71A,DC_2A_n71A

Figure 10-2 The 5G RFT Structure of PTCRB

There should be further detail defined in the upcoming PVG meetings.

10.2 Field Test

Field test could only be performed in certain test area where the real network is already deployed. Operators will provide a road map and locations for the field test in certain cities and certain areas.

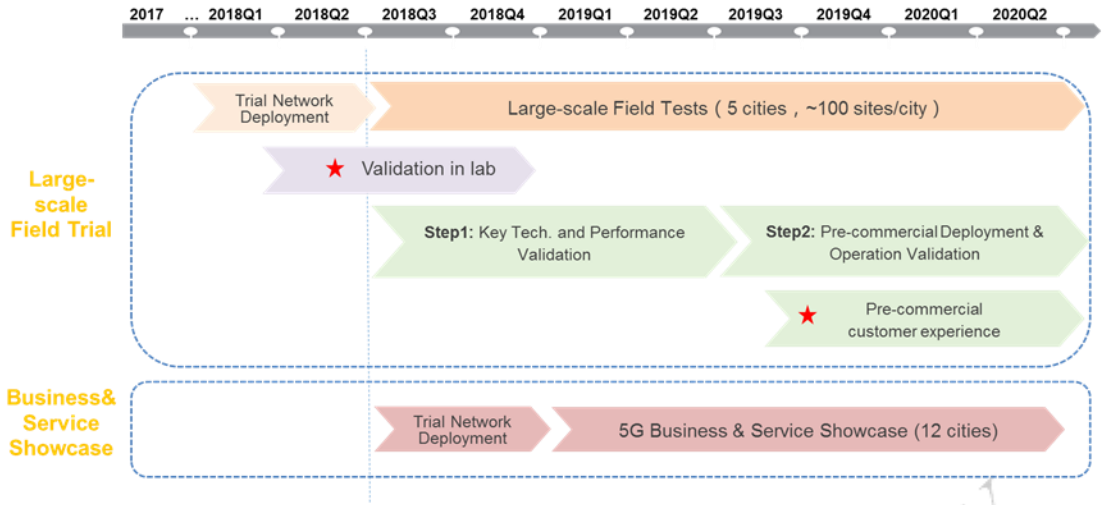


Figure 10-3 The Roadmap of China Mobile's Large-scale Field Trial and B&S Showcase

China Mobile will perform the large-scale trial in 5 cities (Shanghai, Hangzhou, Suzhou, Guangzhou and Wuhan) and the 5G typical application showcase in another 12 cities to facilitate the 5G commercialization.

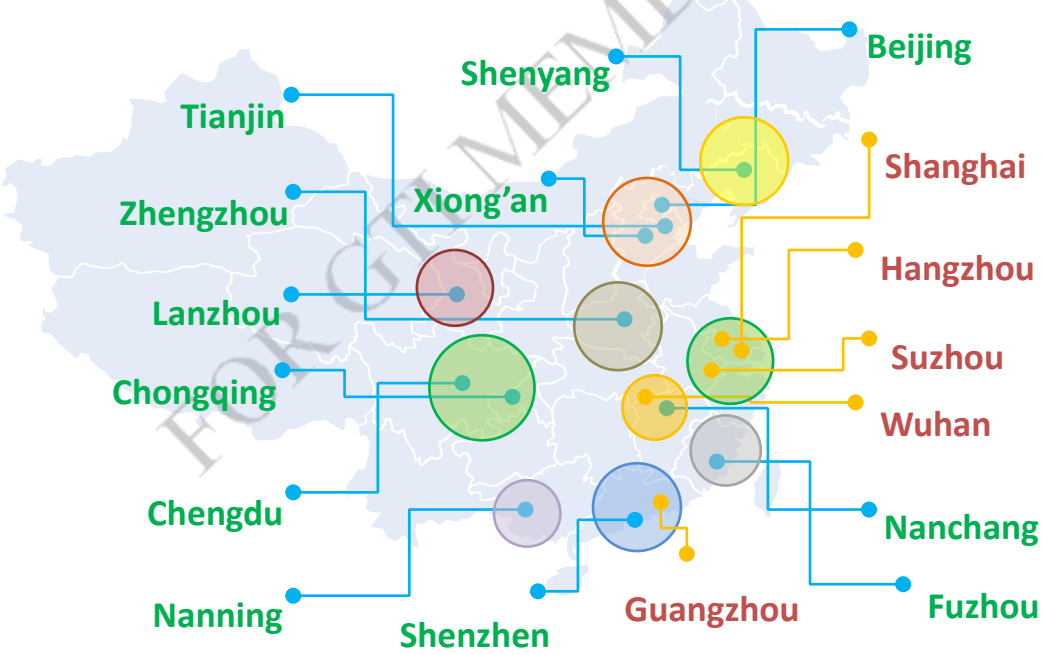


Figure 10-4 The cities for the large-scale Field Trial and B&S Showcase

The figure above shows the 5 cities for the large-scale trial and another 12 cities for the typical application showcase, including 4K Live, Smart healthcare, smart campus, smart manufacturer, robot, livelihood service social management, grid, could gaming, UAV, smart transportation and etc.

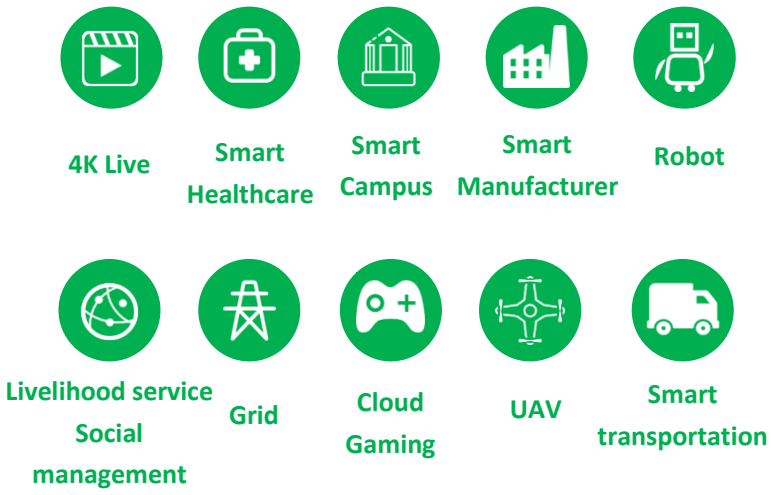


Figure 10-5 The typical application showcases

10.3 Industry Regulatory Test

10.3.1 Regulatory Testing

ETSI is responsible for the development of Harmonized Standards under the Radio Equipment Directive 2014/53/EU (RED) in response to the European Commission (EC) mandates.

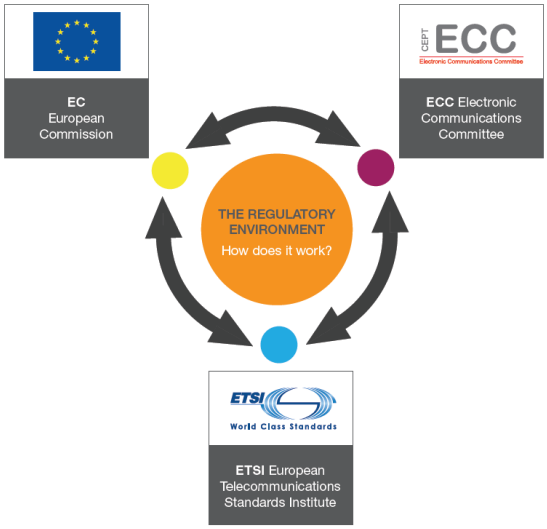


Figure 10-6 European Regulaotry Test Bodies

Harmonized Standards take effect when they are cited in the Official Journal of the European Union. This is available from the EUR-Lex website.

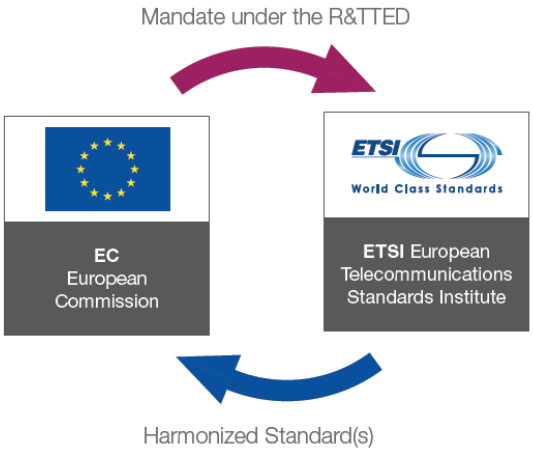


Figure 10-7 R&TTED test regulation

EU regulatory testing

Standard	EU
Radiofrequency (RF)	EN 301 908-1/-13
Electromagnetic Compatibility (EMC)	EN 301 489-1/-24
Electrical Safety (ES)	EN 60950-1
Specific Absorption Rate (SAR)	EN 50360 & EN 62311

Figure 10-8 Regulatory test specifications

ETSI EN 301 908-13: "IMT cellular networks; Harmonized Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 13: Evolved Universal Terrestrial Radio Access (E-UTRA) User Equipment (UE)."

EN 301 908-13 covers the essential requirements of article 3.2 of the Radio Equipment Directive (RED) for E-UTRA UE in addition to those common ones of Part 1.

The Radio Equipment Directive (RED) has replaced the existing Radio & Telecommunications Terminal Equipment Directive (R&TTED) (1999/5/EC), so EU Member States have to adapt their National laws to this new Radio Equipment Directive (RED). Manufacturers who were compliant with the existing legislation (RTTED or LVD/EMCD) had until 13 June 2017 to comply with the new requirements.

EN 301 908-13 currently covers LTE requirements and leverages the contents of the 3GPP TS 36.521-1, with variations in the test requirements. When published, it is expected that the version covering 5G NR will also leverage the contents of the 3GPP TS 38.521-1/2/3 test specifications.

Other countries and regions have their own regulatory requirements that are applicable to mobile devices.

10.4 Carrier Acceptance Test

Finally, certain carrier acceptance tests need to be finished for 5G S-Module. For example, CMCC test in the China area, Sprint certification for North America, Vodafone, Orange, TIM certification for European market.

Besides the traditional carrier acceptance tests for smart phones, such as RF/RRM/SIG test, for 5G S-Modules, carrier acceptance tests will also include the demodulation performance test and power consumption test. For some vertical applications, there will also be voice quality test, service test and even AI test when 5G S-Modules are integrated into the vertical devices.

Some reliability and application tests will also be included, which are very different from the traditional carrier acceptance test and are not so familiar to the traditional communication industry but will be important and necessary to the vertical applications. For example, for the drones, the vibration test, rain test and irradiance test should be necessary to the reliable use. For the Always Connected PC, the high temperature test and the drop test may also be necessary. For some outdoor vertical applications, the working temperature range will be much wider than the consumer electronics (usually -10℃~+40℃), we should make sure that the 5G S-Modules could work normally with a wide working temperature range, such as -40℃~+85℃. So the high temperature test and low temperature test should be necessary.

In a word, carrier acceptance test will have some reliability and application tests for the 5G S-Modules applied in the verticals. For the test cases could not be implemented by the carriers, the certification results of the third-party laboratory could also be considered.

11 The Network Slicing Capability of 5G S-Module

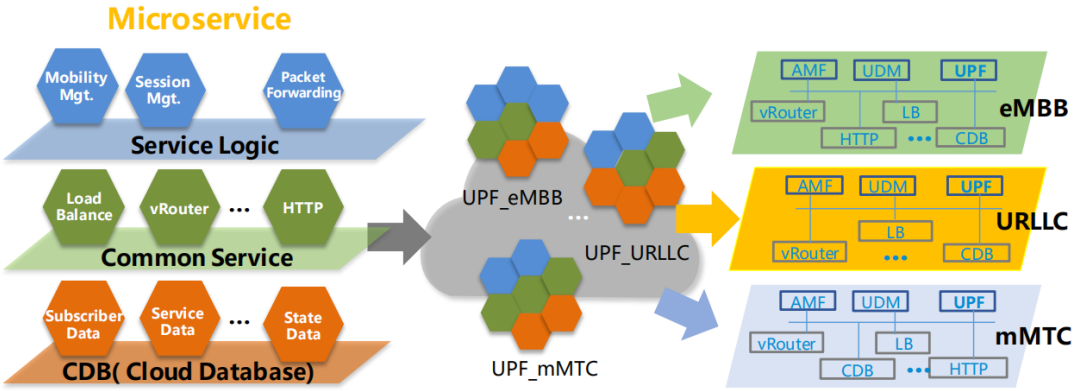
11.1 Application Scenarios

In the 5G era, future business has diversified requirement from the network, for different vertical market, network function has involved different areas, such as smart home, smart grid, smart agriculture, smart meters, autonomous driving, manufacture, energy, financial industry, smart health care, etc. Network service requirement shows more flexible abilities in above areas, to support different connection scenario in different environment. To further exploit the potentials of mobile communication networks depends on the diversified business requirement from these vertical industry. Based on these requirement, network slicing is developed. By network slicing, the carriers could construct multiple proprietary, virtual, isolated logic network based on one general physical platform, to satisfy the different requirements of network capacity from different customers, to improve the network resource efficiency, to form flexible and prompt 5G network.

11.11 Flexible networking by slicing

5G network has three typical scenario, eMBB, URLLC, and mMTC. Network slicing is the symbolic technology that 5G is different from the 4G network. By logic proprietary network to

serve the vertical market, it the strong catcher of the carriers to explore industrial customers, expedite new type business and improve the network value. Generally, mMTC scenario has no requirement to latency and bandwidth, so they could be deployed intensively，to get the advantage of it; eMBB scenario has high requirement of bandwidth, and is different towards latency requirement, CU centralized deployment will be based on latency requirement; and URLLC scenario is strict on the latency, generally will deploy together to lower the loss of transmission latency. So according to the cost, safety and isolation requirement, the core network slice supports multiple sharing type flexible networking.



Network slicing is a new feature that becomes available in 5G option 2 network deployment. Network slices may differ for supported features and network functions optimizations, in which case such Network Slices may have different S-NSSAIs with different Slice/Service Types. Carriers plan to deploy multiple network slice types in the future and deploy URSP policies that route different traffic to different network slices.

5G network slicing could be deployed based on vertical markets (e.g. AR/VR, Internet of Vehicles), regions (provinces, cities, or hot areas), virtual carriers, and the slice layout involves access network, transport network and core network, which are provided by the different equipment vendors, so we face great challenges on the arrangement, deployment and interaction.

11.12 Examples of network slicing scenarios

11.121 Autonomous driving - remote control driving

5G could achieve the real time reliable connection between vehicles and remote platform by network slicing technology. For the remote control driving scenario, the multiple high resolution video from the vehicles should be transferred to the remote driving control platform, which has the following requirement to the communication network: uplink transfer for 50Mbps or higher, and the remote control signal should be transferred to the driver by the 5G ultra low latency network, it must be transferred to tens of miles away within 10ms, thus have the same effect as the driver is inside the vehicle, and the reliability should be >99.999%.

11.122 High precision real time map update and download

When the autonomous driving vehicles have the high accurate maps, they have precise judgement for the environment, which will help the vehicles to have the driving policy in advance. The ideal solution is to let each autonomous vehicle to be a real time map collection unit, by the

crowd sourcing way, to have the real time map update. The requirement of the high precision real time map update is: high uplink bandwidth: >500Mbps.

11.123 AR - Multiple people coordination in the cloud virtual word

The download of the cloud virtual scenario to the local site is the main application scenario of 5G AR, and the multiple people coordination in the virtual reality is the developing product mode of the AR industry top player, in the future, cloud virtual world will be a very important AR application scenario. Virtual world multiple people coordination requires real time scenario uploading, and the interact information could be transfer to other users synchronously, so the important point is for the network to provide high bandwidth and low latency network experience. The higher the bandwidth, the lower the latency, the lower the requirement for data compression and computing demand at both sides, and the lower the power consumption.

11.124 Multi-Party Video Conference System

A high resolution 5G video conference system, could be used for remote control of the factory, it should have very low latency for data transfer. It uses modern communication technology, transfers data, voice, picture in both direction, to fulfill the remote serveice without space restriction, and improves the working efficiency. The high resolution 5G video system successfully implement data transfer without damage and 0 latency, which will help manufacture to collect, transfer, execute, store and inquire the factory management data, which helps remote operation, remote meeting and surveillance, and real-time visit, emergency rescue, etc, network slice for this will efficiently use the network resources.

11.2 Implementation Method

12 The Positioning Capability of 5G S-Module

12.1 Application Scenarios

5G positioning services aim to support various verticals applications. And there are many application scenarios with the requirement of positioning, including mission critical, Location-Based Services, industry and eHealth, road, railway, maritime, aerials, etc. Thus, in this section we summarize the typical positioning application scenarios and this corresponding requirements by vertical. The details are as follows.

12.1.1 Location-based services

Location-Based services refer to general commercial use cases, including positioning for shared bikes and Augmented Reality (AR), power saving of wearable devices, location-based advertising push, and flow management in lager transportation hubs.

Figure 12-1 Location-based services

For shared bikes the accurate positioning enables the mobile APP for the riders to find the nearest bike. And in order to management of bike parking, Electronic fence is used as a tool for regulating the parked bikes, and it requires high accuracy positioning of shared bikes.

Augmented Reality (AR) is enabled by the knowledge of the user's position, motion and eventually, direction of view, and by access, with low latency, to databases of contextual information and geo-localized information systems (GIS). In the field of LBS, AR supports multiple applications, including outdoor sports and leisure activities (skiing, motorcycling, sailing, surfing, rally, aviation and gaming) as well as social networking.

Wearable device applications are becoming more and more grateful, such as smart watches. Smart terminals focus on providing location services and provide better positioning and monitoring functions for these populations. And in order to reduce power consumption of wearable devices, security range can be set. In the security range, the smart terminals can enter power saving mode with lower location update rate.

The development of search engines and Internet advertising, advertising push has become a hot application direction. However people don't want to be bothered by unnecessary advertisements except what they really need. Therefore, data analysis based on human activity location needs to be introduced into location-based advertising push.

Large transportation hubs, such as airports, are getting bigger and busier which calls for efficient flow management to maximize punctuality to the benefit of passengers and airline companies. By using a location-based mobile application, the passengers can easily find their way around, even in unknown airports and in a hurry, reducing time of transit in the airport and lowering risk of delays and missed connections.

12.1.2 Industry and eHealth

In industrial applications, positioning related use cases include assets and moving objects location in factories, waste management and collection and containers handling. And for eHealth, it is necessary to locate the patients, the medical staff and medical equipment (e.g. crash cart). The details of the use cases as follows:

On the factory floor, it is important to locate assets and moving objects such as forklifts, trolleys or parts to be assembled. The assets of factory include plant assets, such as pumps, heaters, instruments, etc., parts to be assembled, production, etc. And to position an object in factory, it is necessary to take into account the environment of factories: buildings have several floors and may have deep basement, some factories are made up of several buildings distributed over several hectares (e.g. campus with large green areas, trees, etc.). In addition, factories may be spread over several sites in vicinity. In this use cases, the horizontal positioning accuracy generally less than [50] cm.

Figure 12-2 Factory positioning

Person and medical equipment location in/out hospitals: In some hospitals like psychiatry or geriatrics, it is necessary to locate the patients in real time on the site of the hospitals (indoor and outdoor) and to notify the medical staff if the patients reach a non-authorised area in order to avoid runaway patients. Additionally, when a patient manages to leave the hospital without authorization, it is necessary to locate him (in a city and in rural area) in order to bring him back to the hospital. In addition, it is necessary to locate caregivers and medical equipment (e.g. crash cart), especially in emergency situations.

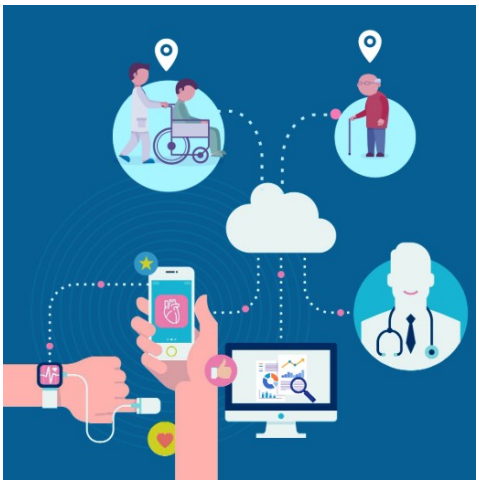


Figure 12-3 Person and medical equipment location in/out hospitals

12.1.3 Emergency and Mission Critical

Accurate positioning for emergency services: An emergency service enables a user to contact a Public Safety Answering Point (PSAP) and requires the emergency services user/UE to have accurate positioning such that they may be located and offered aid by first responders.

Accurate Positioning for First Responders: A mission critical service such as MCPTT enables a first responder to stay in contact with other first responders as well as dispatch and command/control. Mission Critical Organizations require mission critical services to have accurate positioning such that first responders may be located at all times during normal and critical operations.

Alerting nearby emergency responders: In case of a medical emergency, all qualified individuals within close vicinity of the victim get alerted via their phones with a request to provide urgent care. The qualified individuals will often be layman volunteers with a training in first aid.

Life-saving medical equipment, such as AED's, deployed throughout public and private spaces can be localized instantly in case of need, to be able to take the equipment within the minimum possible amount of time to an emergency scene.

Figure 12-4 Emergency and Mission Critical positioning

12.1.4 Road-related positioning

In the road, as vehicles increase, the traffic monitoring, management and control become very significant. The objective to optimize traffic flow when needed and provide feedback to road users to make traffic more fluent. To achieve the objects, the vehicle position needs to be determined with an accuracy able to identify the lane the vehicle is using to decide change or maintain the line. Thus, traffic monitoring have the following potential requirements for network performance: horizontal accuracy is 1meter across-track and 3 meter along-track for UE speed up to the maximum speed, e.g. 130-160 km/h.

Figure 12-5 road-related positioning

The other use case of road is road user charging (RUC) to levying a charge or a tax on the vehicle's user, based on the way the road infrastructure is used by the user. The traditional charging method is static and rigid, and the infrastructure like tollbooth, gantries, etc, cost is huge. The development of positioning technologies allows the implementation of dynamic and flexible RUC services. For example, the RUC algorithms may apply different charging strategies according to traffic condition, lane occupancy or velocity profile. And the premise of this methods is accurate vehicle positioning. And the requirement of positioning horizontal accuracy is 1-3 meter with 1Hz update rate for speed up to 130 km/h

12.1.5 Asset tracking of logistics

Asset tracking is becoming a key capability for worldwide logistics like in the railway or maritime freight sector, e.g. containers, tanks and wagons, etc.

For provides and customers, it provides means to optimize the overall transportation efficiency, and improves end-to-end traceability. Freight tracking enables more accurate scheduling of all involved operations such as departure and arrival time, delays, organization of transshipment, etc. And for freight operators, it eases lean asset management for example, maintenance and retrofit of assets, reduced risks relating to lost or stolen cargos, containers and wagons. Thus, in this scenario the position-related data need to be secured and protected against tampering to dissuade form any unauthorized use, fraud or theft of the transported goods.

The performance requirements of this scenario are as follows: for the static UE, absolute position accuracy is less than 1 meter. The availability is 99% with 1 Hz update rate.

12.1.6 Aerial-related positioning

Unmanned Aerial Vehicle (UAV) or drones for professional or leisure applications are used for several missions, such as, environmental data collection, drones delivery.

For the environmental data collection, the information often is images that are processed to generated added value products. In such a context, the images often need to be geo-localised with a high accuracy in order to allow recombining the images as a sequence of image representing a given scene compared or superimposed onto a ground digital map. For automatic processing of the flow of images, the images and therefore the UAV shall be accurately geo-localised with absolute positions information. In addition, during the landing phase, the UAV operations need also precise 3D geo-localization information in order to allow automatic landing. Therefore, this scenario requires higher positioning accuracy, that is, the horizontal and vertical positioning accuracy is less than 10cm for UE moving at 150km/h outdoor.
For the transport, drones can be applied to logistics delivery and medical supplies. Specifically, for medical purposes, it is necessary to deliver medication, life-saving equipment between two different buildings or hospitals. During the whole delivery process, the position and the status of the drone needs to monitored and logged in order to ensure the full traceability of the delivery, as well as the security of the delivery.

12.1.7 The use cases performances targets

The 5G system shall provide 5G positioning services to satisfy regulatory and verticals application requirements. And the following KPIs apply to the definition of the vertical use cases positioning requirements: the positioning accuracy, delay, availability, Time to First Fix (TTFF) and update rate.
For regulatory use cases, the following requirements are considered as a minimum performance targets for NR positioning [3GPP TR 38.855]:

- Horizontal positioning error <= 50m for 80% of UEs
- Vertical positioning error <5 m for 80% of UEs
- Note: The regulatory requirements of [36] refer to floor level vertical accuracy
- End to end latency and TTFF < 30 seconds

And for the commercial use cases, the above chapters descript the details of the use cases but not give the specific positioning performance requirements. Thus, in this section we summarises the potential performance requirements of the positioning use cases [3GPP TR 22.872].

Table 12.1 – Use cases synthesis

Use cases	Potential requirements per use cases						
	Environment of Use	Position Accuracy	Velocity	Avail.	Update rate or interval	TTFF	Latency
Bike sharing	5G positioning service area - Outdoor	2m Horizontal		90 %		10s	1s
	Enhanced positioning area -	0.2m Horizontal		99 %		10s	1s

	Outdoor						
Augmented Reality	Outdoor - 5G positioning service area	1-3m Horizontal 0.1-3m Vertical	2 m/s 10deg.	80 %	1 - 10 Hz	10s	1s
Wearables	5G positioning service area - -Outdoor/Indoor	2m Horizontal 1-3m Vertical		90 %	30s - 300s	10s	
	5G positioning service area - -Outdoor/Indoor	2m Horizontal 1-3m Vertical		99 %	1s - 30s	10s	1s
Advertisement push	5G positioning service area - -Outdoor/Indoor	3m Horizontal 3m Vertical		90 %			60s
Flow management	Enhanced positioning- Outdoor/Indoor	10m Horizontal		80 %	10s	10s	
Person and medical equipment location in Hospital	Enhanced positioning- Outdoor/Indoor	3m Horizontal 2m Vertical		99 %			60s
Patient location (outside Hospital)	5G positioning service area Outdoor/Indoor	10m Horizontal 3m Vertical (floor)		99 %			
Trolley	Enhanced positioning- Outdoor/Indoor	0.5m Horizontal 1-3m Vertical		99 %			20ms
Emergency call	5G positioning service area Outdoor/Indoor	50m Horizontal 3m Vertical		95 %		30s	60s
Accurate Positioning for First Responders	Outdoor	1m Horizontal, 0.3 m Vertical		98 %		10s	5s
	Indoor	1m Horizontal, 2 m Vertical		95 %		10s	1s
Alerting nearby emergency responders	5G positioning service area Outdoor/Indoor	50m Horizontal 3m Vertical (floor)		99%		10s	
Emergency equipment loc. outside hospitals	5G positioning service area Outdoor/Indoor	10m Horizontal 3m Vertical (floor)		95%		10s	
Traffic Monitoring & Control	5G positioning service area - Outdoor	1-3m Horizontal 2.5m Vertical		95 %	10 Hz	10s	30ms
Road User Charging	5G positioning service area - Outdoor Enhanced positioning-Tunnels	<1m (across track) 3m (along track)	2 m/s	99 %	1 Hz	10s	
Asset tracking and management	5G positioning service area - Outdoor	10-30m Horizontal	5 m/s	99 %	300s-1day		
	Enhanced positioning - Outdoor	1m Horizontal		99 %	1s	1s in enhanced positioning area	
UAV (Data analysis)	5G positioning service area - Outdoor	0.1m Horizontal 0.1m Vertical	0.5 m/s 2 deg.	99 %		10s	

UAV (Remote control)	5G positioning service area - Outdoor	0.5m Horizontal 0.3m Vertical		99 %			150ms
	Enhanced positioning area - Outdoor	0.5m Horizontal 0.1m Vertical		99.9 %			150ms
	Enhanced positioning area - Indoor	0.1m Horizontal		99 %		10s	1s

12.2 Implementation Method of Outdoor positioning

12.2.1 GNSS Overview

12.2.1.1 GNSS Introduction and Overview

GNSS stands for Global Navigation Satellite Systems. GNSS is the standard generic term for satellite navigation systems to provide autonomous geo-spatial positioning with global coverage. GNSS allows the receivers to determine their location (longitude, latitude, and height) to within a few meters using the signals as transmitted by the GNSS satellites. In the same process the receivers also calculate the precise time of the signal reception and as such GNSS receivers can be used as highly accurate clocks.

GPS is the fully operational GNSS. The Russian GLONASS is a GNSS being restored to full operation. The European Galileo positioning system is a next generation GNSS in the initial deployment phase. China has expanded regional Beidou (also called COMPASS) navigation system into a global system. India's IRNSS, is also a next generation GNSS. However, its status and future is unclear as India seems to have entered into a close cooperation with the Russians on the GLONASS system.

GPS is the primary satellite navigation system world wide for determining position and time information. The applications of satellite based positioning and timing are manyfold. They included maritime and aircraft navigation, fleet management, private car navigation, communications system time synchronization, and also high-accuracy (few mm level) geo-surveying.

12.2.1.2 Basic Principle of GNSS

The basis of all GNSS systems is that a user determines it position by measuring to at least 4 GNSS satellites at the same time. These measurements give the user 4 distance measurements between himself and the 4 satellites. With four measurements one can resolve 4 unknowns. For the end user these 4 unknowns are the 3 unknowns of his position (X, Y, and Z or Latitude, Longitude, and Height) and the clock error of his GNSS receiver.

12.2.1.3 GNSS Measurement Corrections

We have 4 distance measurements and they all end at the same point, the location of the receiver. With the 4 distance measurements and the satellite positions we can determine the location of our receiver and its clock offset. The GNSS signal travel with the speed of light as long as they are in the vacuum of space. In the Earths atmosphere the signals get disturbed. Firstly, in the ionospere, the upper layer of the Earths atmosphere (~above 50km). Secondly, in the troposphere, the lower 50km of the Earth's atmosphere.

The effect of the ionosphere may be correct by using signals on two frequencies. The broadcast navigation message, which gave us the satelite position and the clock errors, also gives us a model for the ionosphere, called Klobuchar model. The ionospheric delays on the signal are of the order of tens of meters. With the Klobuchar model the ionospheric effects can be modeled with meter level precision.

The tropospheric effect can also be accounted for by using a model. For a measurement in zenith (straight up) the tropospheric delay is of the order of 2 meters. For low elevation measurements this effect grows to the level of 10 meters due to the longer time the signal has to travels through the tropospere. The main unknown in the tropospheric delay is the amount of water vapour in the air. However, with a relatively simple model the effect of the troposphere can be modeled at the sub-meter level.

12.2.1.4 GNSS Position Estimate

We have 4 measurments with an accuracy of about 1 meter. Thus we are able to compute our position with a few meter accuracy. And that is what GNSS offers us at anytime, anywhere on earth.

12.2.2 GNSS Implement Introduction

GNSS is implemented in the module by a GNSS chipset, GNSS function could be easily realized by AT command interface provided in the USB and UART interface. Following are some GNSS features supported in the module

- Support S-GPS and A-GPS function.
- Support GLONASS function.
- Support BEIDOU function
- Support standalone mode, MS-based mode and MS-assisted mode
- Support cold start and hot start.
- Support a subset of the NMEA-0183 standard.
- Support NMEA sentences output in NMEA port port.
- A-GPS supports UP (user plane) and CP (control plane) method.
- MS-assisted mode supports single fixed; MS-based mode supports seriate fixed.

- Support certificate if necessary.

Supporting GPS starts automatically when module powers on, it supports standalone mode only.

12.2.2.1 GPS Mode Introduction

In MS-assisted mode, when a request for position location is issued, available network information is provided to the location server and assistance is requested from the location server. The location server sends the assistance information to the handset. The handset/mobile unit measures the GPS observables and provides the GPS measurements along with available network data (that is appropriate for the given air interface technology) to the location server. The location server then calculates the position location and returns results to the requesting entity.

In MS-based mode, the assistant data provided by the location server encompasses not only the information required to assist the handset in measuring the satellite signals, but also the information required to calculate the handset's position. Therefore, rather than providing the GPS measurements and available network data back to the location server, the mobile calculates the location on the handset and passes the result to the requesting entity.

In standalone mode, the handset demodulates the data directly from the GPS and GLONASS satellites. This mode has some reduced cold-start sensitivity, and a longer time to first fix as compared to the assisted modes. However, it requires no server interaction and works out of network coverage. GPS is preferred than GLONASS, so if GPS has fixed the position, the GNSS engine will close GLONASS, in order to save the power. If customer wants GPS and GLONASS hybrid, he can first change the mode with AT Command. BEIDOU is opened default, you can close it through AT Command.

12.2.2.2 A-GPS Quick Start

We need to configure A-GPS setting to start. First, we need to set A-GPS server address, A-GPS server and PDP context profile must be set. The server address is provided by local carrier. Then we need to set certificate. If the GPS server requires certificate, we must select security mode, and input the certificate. The certificate must be imported into EFS by PC tool. Then we need to select the transport security: The certificate is provided by local carrier.

12.2.2.3 Start GPS

(1) Start GPS Standalone Mode

Three methods can start GPS standalone mode:

1. AT+CGPS=1,1 (or AT+CGPS=1)
2. AT+CGPSCOLD
3. AT+CGPSHOT

These commands must be executed after GPS engine switched off.

GPS started should be decided by the physical switch of GPS flight mode in the module firstly. Close the switch, GPS will be started automatically, then you can open or close gps by AT command, otherwize, GPS could not be started in any way.

(2) Start A-GPS Mode

When using MS-based mode, mode will transform to standalone mode automatically after getting the ephemeris information from the server. MS-assisted mode is single fixed; MS-based mode is seriate fixed.

12.2.2.4 Get GPS Position Information

(1) Standalone Mode

Command AT+CGPSINFO will return fixed position; also it can report GPS position string automatically by configured with AT command.

The report format:

+CGPSINFO: 3113.393766,N,12121.176625,E,061108,075358.0,19.5,0

(2)A-GPS Mode

If MS-based mode is enabled, fixed position information is like standalone mode.

If MS-assisted mode is enabled, GPS position string will report automatically.

The report format is as following:

+CAGPSINFO:3122256517,12135328531,135,15052009,012749.0

For the modules which support GPS, and also support GLONASS, BEIDOU/Galileo, its assistant for TTFF and GPS is opened by default, you can use AT Command to close/open them.

12.2.3 GNSS Implementation

For the modules based on Qualcomm chipset, module could enable BDS/Galileo/QZSS/NavIC when a mobile device is outside the geographical boundaries of the U.S. It explains the reasons for enablement, and modified use of the GNSS constellation configuration NV item. All supported constellation setting was configured by this NV. Here we discusses the performance impacts of the change. The module will support BeiDou/GAL/QZSS/NavIC positioning.

QTI has added support for BeiDou Navigation Satellite System (BDS), Galileo Satellite System (GAL), Quasi-Zenith Satellite System (QZSS), and Navigation with Indian Constellation (NavIC), and is now able to leverage the benefits of these satellite systems in a position solution to improve the overall performance of the receiver. Due to the regulations in the U.S., certain foreign GNSS systems may not be allowed to use on handsets located in the U.S.

■ BDS/QZSS/NavIC: QTI software uses a method to automatically detect the location of the receiver and dynamically allow the usage of the BDS/QZSS/NavIC signals when the receiver is outside the U.S.

■ GAL: Like the BDS/QZSS/NavIC signals, the same method is implemented for GAL not to allow the usage of GAL signal if the receiver operated within the geographical boundaries of the U.S.

In April 2019, U.S. Federal Communications Commission (FCC) approved an order that allows the devices in the U.S. to use the GAL E1/E5 signals for navigation services while

these signals are not allowed for use in the E911 scenario. The QTI software is modified to allow GAL usage targets in geographical boundaries of the U.S. and keep GAL disabled in E911 sessions when the user equipment (UE) is located within the geographical boundaries of the U.S.

For Beidou enablement, there are following impacts:

■If the receiver is outside the U.S., the first GNSS fix after every power-on will not use BDS SVs. After the first fix, if it is confirmed that the receiver is operating outside the geographical boundaries of the U.S., BDS is enabled and subsequent fixes reflect the performance improvements due to BDS.

■ If the receiver is physically located in the U.S., BDS SVs are not used in a position fix. This limits the SVs to GPS and GLONASS only. However, this should not cause noticeable impact in the performance, since BDS SV visibility is low in the U.S. region and BDS is not visible all the time.

GAL usage is not allowed in US by default:

The software performs a boundary check for successful GNSS fix to determine if UE is within the U.S. region. If the location of UE is unknown or confirmed to be within the U.S.:

GAL measurements are not generated and GAL SVs are not used in a GNSS solution.

GAL navigation data is not decoded or transferred to other systems.

If the receiver is not in the U.S. region:

GAL measurements are generated and SVs are used in the position computation.

Information of GAL, such as time, is decoded and used for receiver operation.

When GAL is enabled and used without considering the regional restrictions. GAL measurement is sent throughout the GNSS sessions. GAL is enabled and used in E911 and non-E911 scenario.

GAL enablement must be authorized by U.S. FCC for a specific mobile carrier (or)

GAL enablement is necessary for controlled testing using a limited number of devices to get the approval of U.S. FCC for E911 purpose.

When GAL USAGE is DISABLED:

GAL must not be used. No acquisition or tracking of GAL

12.2.4 Other Outdoor Positioning Method

12.2.4.1 E-CID positioning method

In the Cell ID (CID) positioning method, the position of an UE is estimated with the knowledge of its serving cell. The information about the serving cell may be obtained by paging, registration, or other methods.

Enhanced Cell ID (E-CID) positioning refers to techniques which use additional UE measurements and/or radio resource and other measurements to improve the UE location estimate.

For E-CID positioning methods the UE reports only the measurements that it has available rather than being required to take additional measurement actions. The operation of the Enhanced Cell ID can be based on LTE signals as well as 5G NR signals.

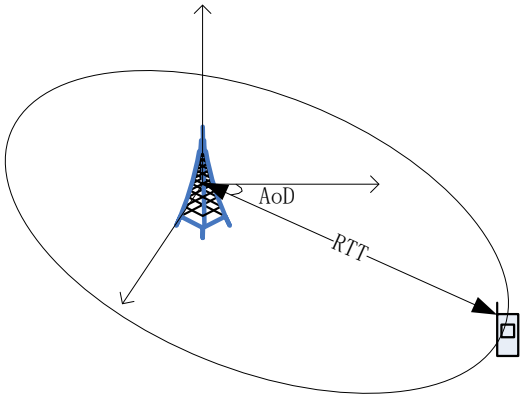


Figure 12.2.3-1 E-CID positioning

12.2.4.2 Multi-RTT positioning method

In the Multi-RTT positioning method, the UE position is estimated based on measurements performed at both UE and TRPs. The UE measures the UE Rx-Tx measurements using assistance data received from the positioning server, and the TRPs measure the gNB Rx-Tx measurements using assistance data received from the positioning server. The measurements are used to determine the RTT at the positioning server which are used to estimate the location of the UE.

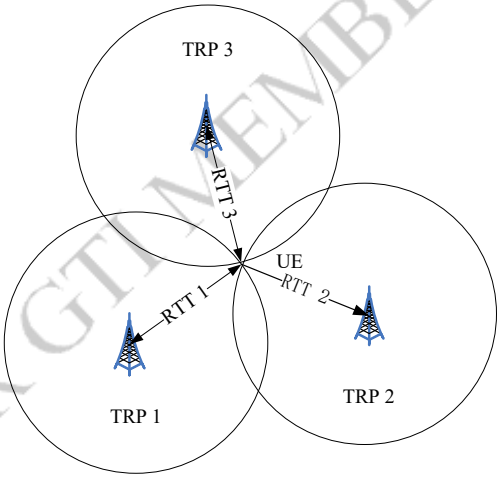


Figure 12.2.4-1 Multi-RTT method

12.2.4.3 DL-AOD positioning method

The DL AOD positioning method makes use of the measured DL PRS RSRP of downlink signals received from multiple TPs, at the UE. The UE measures the DL PRS RSRP of the received signals using assistance data received from the positioning server, and the resulting measurements are used along with other configuration information to locate the UE in relation to the neighboring TPs.

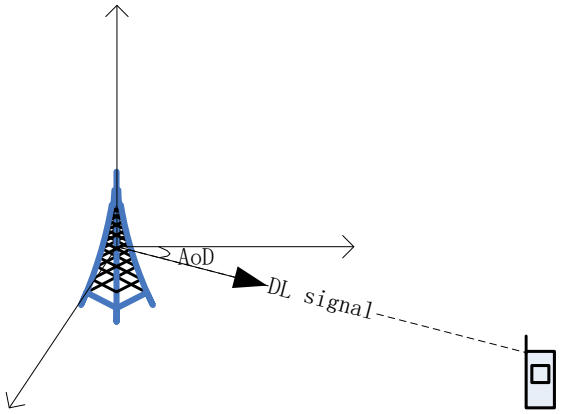


Figure 12.2.5-1 DL-AOD method

12.2.4.4 DL-TDOA positioning method

The DL TDOA positioning method makes use of the DL RSTD of downlink signals received from multiple TPs, at the UE. The UE measures the DL RSTD of the received signals using assistance data received from the positioning server, and the resulting measurements are used along with other configuration information to locate the UE in relation to the neighboring TPs.

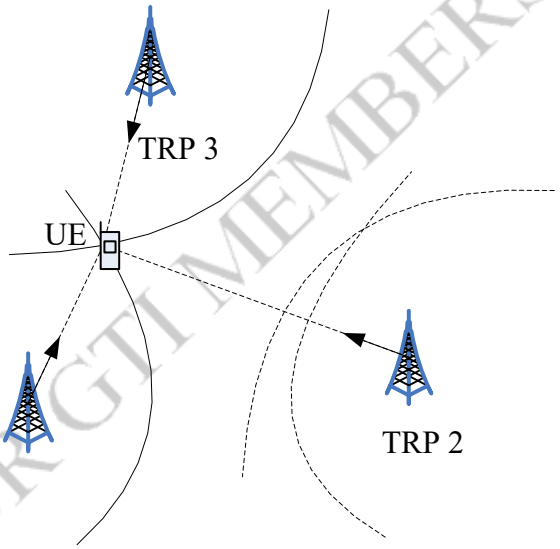


Figure 12.2.6-1 DL-TDOA method

12.2.4.5 UL-TDOA positioning method

The UL TDOA positioning method makes use of the UL TDOA at multiple RPs of uplink signals transmitted from UE. The RPs measure the UL TDOA of the received signals using assistance data received from the positioning server, and the resulting measurements are used along with other configuration information to estimate the location of the UE.

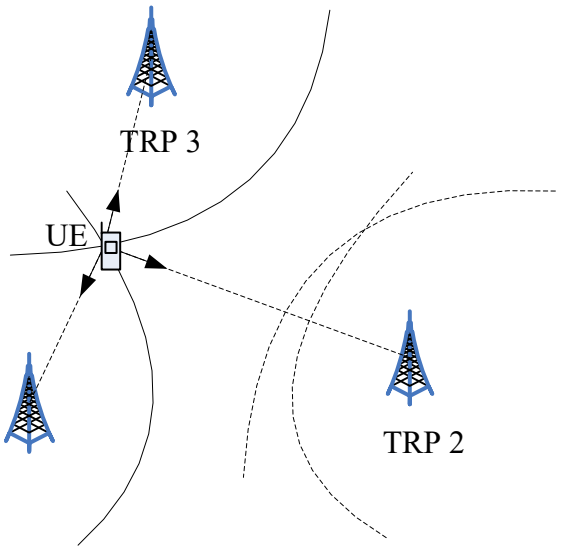


Figure 12.2.7-1 UL-TDOA method

12.2.4.6 UL-AOA positioning method

The UL AoA positioning method makes use of the measured azimuth and zenith of arrival at multiple RPs of uplink signals transmitted from the UE. The RPs measure A-AoA and Z-AoA of the received signals using assistance data received from the positioning server, and the resulting measurements are used along with other configuration information to estimate the location of the UE.

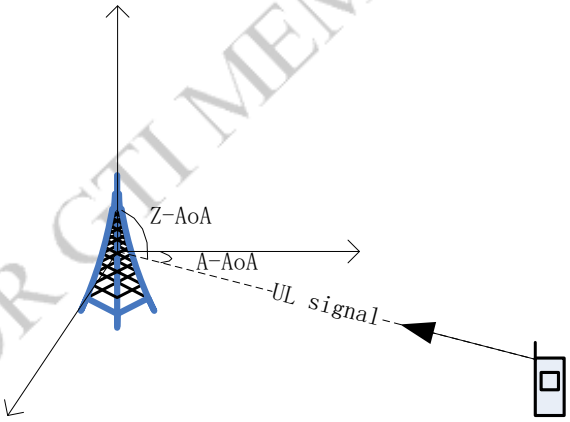


Figure 12.2.8-1 UL-AOA method

12.2.4.7 TBS positioning method

Terrestrial Beacon Systems (TBS) is the standard generic term for a network of ground-based transmitters broadcasting signals for geo-spatial positioning with wide-area or regional coverage. A Terrestrial Beacon System (TBS) consists of a network of ground-based transmitters, broadcasting signals only for positioning purposes. The current type of TBS positioning signals can be the MBS (Metropolitan Beacon System) signals and Positioning Reference Signals. The UE measures received TBS signals, optionally aided by assistance data, to calculate its location or to send measurements to the positioning server for position calculation.

12.2.4.8 Barometric sensor based positioning method

The barometric pressure sensor method makes use of barometric sensors to determine the vertical component of the position of the UE. The use of barometric sensors for identifying height information is motivated by the fundamental property that atmospheric pressure drops with an increase in altitude. The UE measures barometric pressure, optionally aided by assistance data, to calculate the vertical component of its location or to send measurements to the positioning server for position calculation. In the barometric pressure sensor positioning method, the UE vertical component of the position is estimated by combining the measured atmospheric pressure and a reference atmospheric pressure. This is accomplished through barometric sensors measuring atmospheric pressure at the UE, and applying a height determination algorithm using the reference atmospheric pressure. Therefore, this method should be combined with other positioning methods to determine the 3D position of the UE.

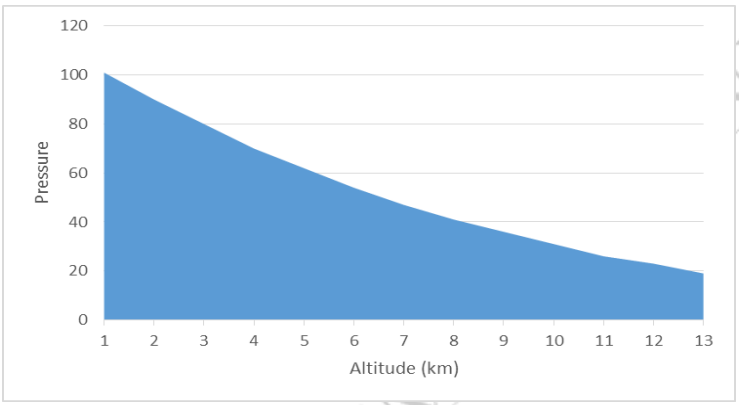


Figure 12.3.4-1 Relationship between atmospheric pressure and altitude

12.2.4.9 Motion sensor based positioning method

The motion sensor method makes use of different sensors such as accelerometers, gyros, magnetometers, to calculate the displacement of UE. The UE estimates a relative displacement based upon a reference position and/or reference time. UE sends a report comprising the determined relative displacement which can be used to determine the absolute position.

This method should be used with other positioning methods for hybrid positioning. With the combination of other positioning methods (hybrid) a more accurate position of the UE can be computed. UE using one or more motion sensors provides the movement information. The movement information comprises displacement results estimated as an ordered series of points.

12.2.5 Indoor positioning Implementation Method

12.2.5.1 E-CID positioning method

The general description of E-CID positioning is provided in clause 12.2.1. For indoor positioning, the serving cell only covers a small area. LOS link can be expected between UE and the serving cell, which will result in a more accurate additional measurement. Therefore, E-CID method is a promising solution to achieve good positioning performance while maintaining low complexity.

12.2.5.2 Multi-RTT positioning method

The general description of multi-RTT positioning is provided in clause 12.2.2. For indoor positioning, multiple TRPs will be distributed implemented within the indoor scenario. With the large number of indoor TRPs, more RTT measurements can be performed. Also, the small distance and high LOS probability between UE and each TRP will result in a more accurate RTT measurement, and consequently a more accurate Multi-RTT positioning estimate.

12.2.5.3 DL-AOD positioning method

The general description of DL-AOD positioning is provided in clause 12.2.3. For indoor positioning, the serving cell only covers a small area. LOS link can be expected between UE and the serving cell, which will result in a more accurate DL-AOD estimate.

12.2.5.4 DL-TDOA positioning method

The general description of DL-TDOA positioning is provided in clause 12.2.4. For indoor positioning, multiple TRPs will be distributed implemented within the indoor scenario. Similar as for Multi-RTT positioning method, large number of indoor TRPs with small distance between UE and each TRP will result in a more accurate DL RSTD measurement, and consequently a more accurate DL-TDOA positioning estimate.

12.2.5.5 UL-TDOA positioning method

The general description of UL-TDOA positioning is provided in clause 12.2.5. For indoor positioning, multiple TRPs will be distributed implemented within the indoor scenario. Similar as for Multi-RTT positioning method, large number of indoor TRPs with small distance between UE and each TRP will result in a more accurate UL RTOA measurement, and consequently a more accurate UL-TDOA positioning estimate.

12.2.5.6 UL-AOA positioning method

The general description of UL-AOA positioning is provided in clause 12.2.6. For indoor positioning, the serving cell only covers a small area. LOS link can be expected between UE and the serving cell, which will result in a more accurate UL-AOA estimate.

12.2.5.7 TBS positioning method

The general description of TBS positioning is provided in clause 12.2.8. For indoor positioning, a large number of ground-based transmitters can be implemented within the indoor scenario. The positioning accuracy can be improved by better hearability and higher LOS probability. Also, UE can measure outdoor transmitters together with indoor transmitters to achieve better performance.

12.2.5.8 Barometric sensor based positioning method

The general description of barometric sensor based positioning is provided in clause 12.2.9. For indoor positioning, barometric sensor can be used to determine which floor a UE is located in a building. In order to estimate the floor information, reference atmospheric pressure for each floor should be provided for the UE.

12.2.5.9 Motion sensor based positioning method

The general description of motion sensor based positioning is provided in clause 12.2.10. For indoor positioning, motion sensor can be used to determine the relative displacement, moving direction and the speed of a UE within the indoor area. For the UE equipped with motion sensor, the implementation method of indoor positioning is the same as for outdoor positioning.

12.2.5.10 WLAN based positioning method

The WLAN positioning method makes use of the WLAN measurements (AP identifiers and optionally other measurements) and databases to determine the location of the UE. The UE measures received signals from WLAN access points, optionally aided by assistance data, to send measurements to the positioning server for position calculation. WLAN based positioning is usually accomplished by collecting RSSI and other information from the UE's Wi-Fi receiver, and applying a location determination algorithm using databases of the estimated positions or coverage areas of Wi-Fi access points.

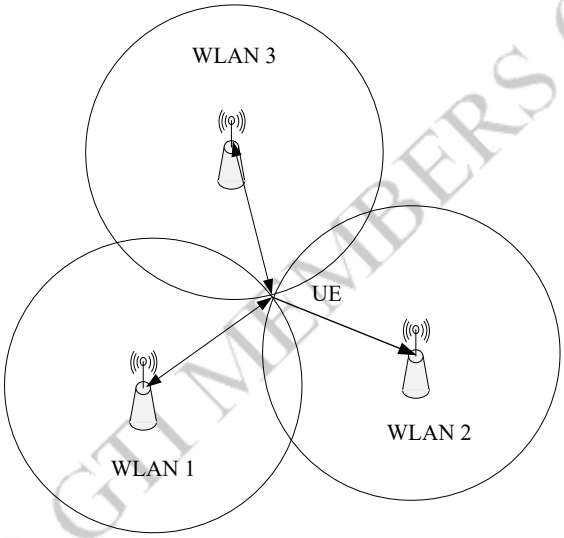


Figure 12.3.10-1 WLAN based positioning

12.2.5.11 Bluetooth based positioning method

The Bluetooth positioning method makes use of Bluetooth measurements (beacon identifiers and optionally other measurements) to determine the location of the UE. The UE measures received signals from Bluetooth beacons. Using the measurement results and a references database, the location of the UE is calculated. The Bluetooth methods may be combined with other positioning methods (e.g. WLAN) to improve positioning accuracy of the UE.

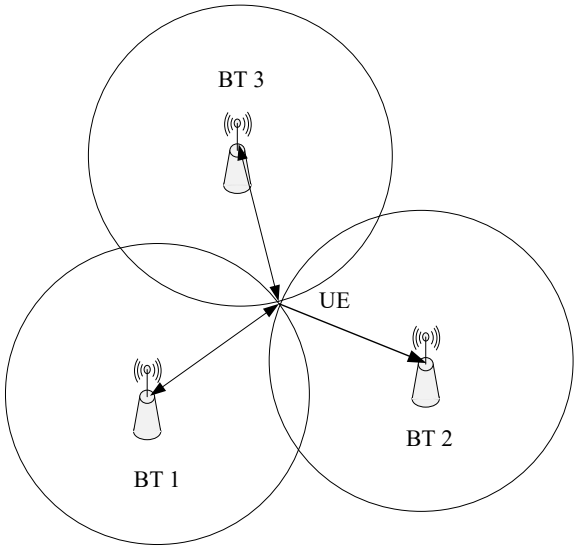


Figure 12.3.11-1 Bluetooth based positioning

13 Typical Application Scenarios for 5G S-Module

The 5G S-Module will use the most cutting-edge technology and give device vendor a chance to develop their application easily, therefore, we summarize the different typical application scenarios for 5G S-Module to meet the customer's requirements are as below.

13.1 5G S-Module Basic Type-L

13.1.1 Smart Factory – Robot

Mobile robots and mobile platforms have numerous applications in industrial and internal logistics environments and will play an increasingly important role in future factories. Mobile robot systems are characterized by maximum mobility relative to the environment, with a certain degree of autonomy and perceptive ability, that is, they can perceive and respond to their environment, and controlled by central system.

Mobile robot systems can operate in indoor and outdoor areas. These environmental conditions have an impact on the requirements of the communications system to ensure the required cycle time, and the main use of the interior is the transport of semi-finished products of light cargo, possibly in different plants. The outdoor application can be the transport of the port's container of unit-load vehicles, or for the large farms. Indoor and outdoor refers to the combination of factory buildings and open areas, such as traction vehicles, cows/animal-feeding robots on farms, etc.

Mobile robots have the following potential requirements for network performance: the requirements for delay, availability of communications services, and certainty are stringent. Communication service availability is 99.9999% with ms-grade delay requirements. For example, for precision collaborative robot motion control, the delay will be 1ms, while for remote control for video operation, it will be 10ms to 100ms. The data transmission rate of each mobile robot will be bigger than 10 Mbps. The ground speed of user equipment up to 50 km/h, and it should support interfaces for reliability monitoring.

5G S-Module Type-L could meet this requirement and it will be reliable and efficient. Currently, for a factory or farm, 5G S-Module Type-L could be put into each robot system and communicate with control center.

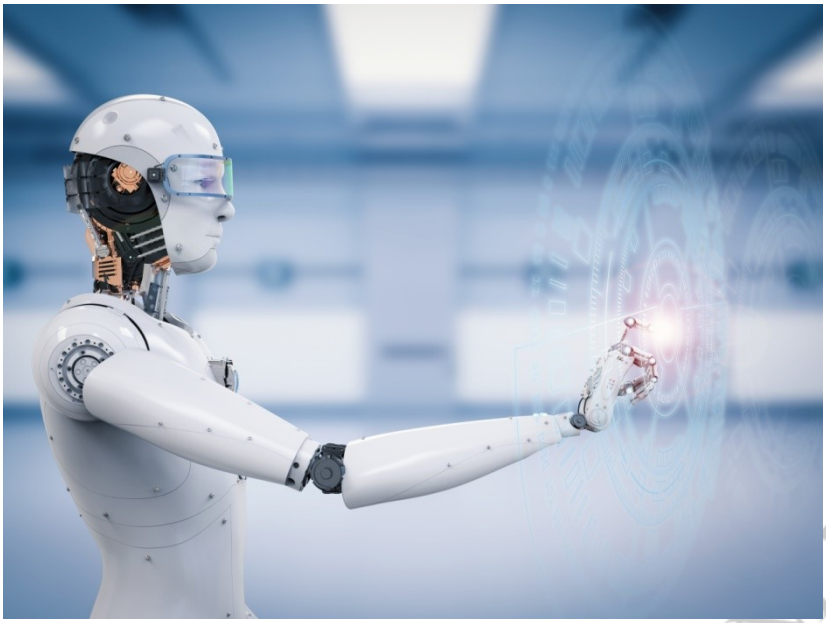


Figure 11-1 Mobile robots

13.1.2 Connected Energy – Industrial Routers

There is a large demand of industrial routers with strong and stable performance. It should support wireless standard of 650MHZ, with large capacity DDR2 RAM and high speed S PI Flash, with 300Mbps 2.4g wireless network. It will provide at least five 10/100M self-adapted Ethernet interface, with USB3.0 or above router interface, and it will provide rich industrial communication interfaces, such as RS232, 485, 5G dialing, electrical relay control, IO output interfaces with or without latch function, to satisfy various industrial application requirement with high performance. The wireless requirement of industrial routers should conform to IEEE802.11n/g/b wireless network protocol, and adopt 4x4 MIMO (Multiple Input Multiple output) architecture. The wireless transfer rate should be over 300Mbps, with two 2.4G antennas and four 5G antennas. The wireless signal coverage should be bigger than 50 meters and with the theoretical capacity of 30 connected devices.

5G S-Module could easily replace the 4G modules in the industrial routers and with much higher performance. It will have higher data ratio, with less delay, and work for connecting more devices. It will be a new direction to improve the industrial routers' quality and provide more functions.

Figure 11-2 Industrial Routers

13.1.3 UHD 8K Online Video & living broadcast

The typical scenarios Basic Type-L could be applied in UHD 8K Online Video or living broadcast. In 2018, enterprises launched display systems supporting 8K Super High Definition (SHD). Currently, where mobile phone screens have become the "first screen" for individuals, SHD online video supported by 5G technology will add mobile features for 8K technology. In addition, video sharing on mobile social networks, especially popular live broadcast platforms, will greatly benefit from the online live broadcast capacity using 5G technology. Now, 5G S-Module Basic Type-L can be integrated into 5G Terminals to fully meet these requirements.

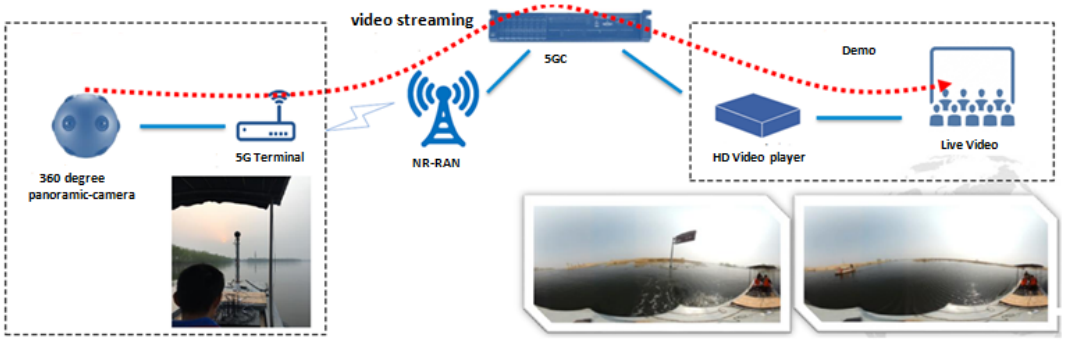


Figure 11-3 UHD 8K Online Video & living broadcast

13.1.4 Wireless eHealth

Remote diagnostics plays a more and more important role in modern life. With the growth of aging population the increase of sufferers of chronic diseases and the shortage of medical resources emerge. Also, , with the rapid pace of modern life, it is time consuming for the young people to go to the hospital and wait in the long line. Therefore, the service model of health care will be changed. The development of the Internet of Things has provided essential conditions for smart medical care. The introduction of mobile devices using M2M communication modules plays a substantial role in the prevention, diagnosis, treatment, and monitoring fields. Remote diagnosis can be used to diagnose the patient's condition. This new Mobile Healthcare (mHealth) medical model not only reduces labor and material costs, but also combines various types of mobile devices, such as smart phones and tablet PCs. With the applications are available on the mobile devices, it is now possible to keep track of the health status and improve the reliability of medical care.

5G S-Module Basic Type-L can be used in the diagnostic devices with high performance, which

will enable the devices for remote video. Thus, doctors can use these devices to monitor patients' health conditions. With high data rate and low latency, it could bring a revolution for remote diagnostics.

Figure 11-4 Wireless eHealth

13.1.5 FWA

FWA (Fixed Wireless Access) is a concept for providing broadband service to homes and small and medium-sized enterprises (SMEs) that is particularly attractive in cases where there is no infrastructure in place to deliver wired broadband via copper, fiber or hybrid solutions. It can also be used when the existing infrastructure is not able to provide sufficient service. With 5G which can provide 10 to 100 times more capacity than 4G, it has the potential to enable cost-efficient FWA solutions on a massive scale. The 5G S-Module Basic Type-L can be easily integrated into CPE devices used for FWA.

Figure 11-5 Fixed Wireless Access

13.1.6 Video Surveillance

With 4G wireless network transmission, surveillance devices can perform video surveillance in the mobile environment, such as police patrol car surveillance, traffic police surveillance, and personnel mobile command. 5G technology will further expand the applicability of SHD video surveillance in emergency response scenarios including urban security, urban emergency management, and major accident live broadcasting. For example, the current technology

implements 4M video surveillance for trains and subways, which is poor in timeliness and clarity. 5G eMBB scenario, featuring high data rate, will provide new technical support for scenarios like this. According to calculations, video surveillance at 6M, 8M pixels or even 4K resolution requires bandwidth above 50MHz, while real-time HD images at 8K 60fps require transmission bandwidth above 120MHz. 5G S-Module Basic Type-L can fully fulfill the requirements and be easily integrated into surveillance devices such SHD camera.

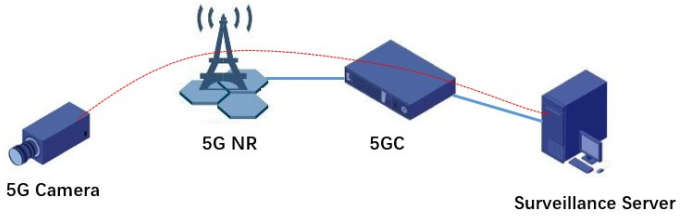


Figure 11-6 SHD video surveillance through 5G Network

13.1.7 AR/VR

According to Gartner, the use of VR and AR is one of six top technology workplace trends that will drive the digital workplace and “are ready for mainstream businesses”. At present, the huge amount of computation and storage AR/VR requirements restrict low cost of terminal devices and fast growth of related applications. The integration of 5G and cloud computing provides an evolution for VR/AR. Real-time content downloading, real-time modeling and rendering will provide the ultimate experience for mixed reality applications. Moving computing and storage to the cloud will greatly reduce the cost of the terminal devices. Meanwhile, 5G ultra-high-bandwidth and ultra-low-latency networks are responsible for transmitting the large amounts of data. 5G S-Module Basic Type-L can be used in VR/AR devices to meet the needs of devices requiring ultra-high bandwidth and significant data transmission.

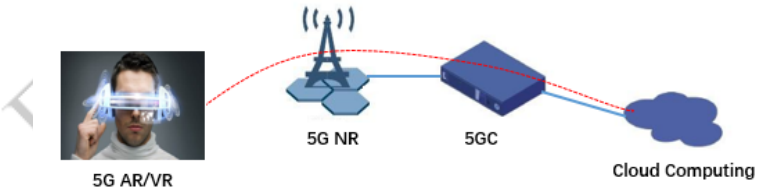


Figure 11-7.8 Cloud AR/VR

13.2 5G S-Module Basic Type-M

13.2.1 Laptop industry and sky office application

Basic Type-M could be applied in Laptop industry, which is one of the typical scenarios, and in 2018 PC already integrated Cat 16 LTE module. In the next generation Laptop need module to support higher data rate for downlink and uplink.

The features of 5G type-M module such as high data rate, low latency, and safety will bring an opportunity for innovation of office. At the same time, 5G makes it possible to work anytime, anywhere, such as keeping online on the high-speed train with the 350-500km/h speed. Laptops with 5G modules will synchronize with cloud, and achieve some user cases such as file management in cloud, cloud coordination, remote HD meetings, upgrading normal PC + high end display to work station and so on. The application scenarios are shown in Figure 11-8. Also, unlimited data plan from the operators will become the main trend to stimulate the usage of 5G laptop.

Figure 11-8 the Application Scenario of 5G S-Module Basic Type-M

The 5G S-Module Basic Type-M need meet PCIE M.2 Electro-Mechanical Card specification, revision 1.1 and RF part meet release 15 NSA and release 16 SA. It had better be a single hardware SKU with support for worldwide coverage and certification on networks. It also shall support external 4x4 MIMO antennas for 5G MR-DC (Multi Rats dual connectivity).

For software the 5G S-Module Basic Type-M shall support Operator Name String (EONS), PAP/CHAP, USSD, PCSC SIM authentication OMA-DM, OTA-DM, static IP SIM, diagnostic, activation, Multi-IMSI SIM, Roaming Broker, and shared network, SPN (Service Provider Name) display etc. With these features, 5G S-module could easily replace the 4G modules in the laptop and with much higher performance.

13.3 5G S-Module Smart Type

13.3.1 Smart POS

Smart hardware is represented by unmanned retail, smart POS and unmanned containers. These aspects require a lot of man-machine interaction and M2M work, including advertisement, identification of user behavior and payment security. Smart POS (Smart Point of sales, also called micro POS)is a new concept versus the traditional POS. Its main functions include the traditional POS functions such as scanning bar code, swiping the card. It can also scan two-dimensional bar code, member cards verification and customer management via CRM system and big data analysis. Its main task is electrical payment, which will replace the cash payment.

Smart POS are mainly divided into two categories: desktop smart POS and portable smart POS according to their size. They are also categorized as keypad type and touch screen type. Smart POS generally are customized on Android system. Portable smart POS starts a new era of mobile payment system, which will improve customer satisfaction. The 5G S-Module Smart Type can meet Smart POS requirements. POS manufacturers need only add a colored screen in order to make a Smart POS.

Figure 11-9 Smart POS

Firstly, 5G S-Module Smart Type could lower the cost for Total BOM, because the cost of Smart Modules will be less than “AP + standard Modem”. Secondly, 5G S-Module Smart Type has abundant functions with Modem/Wi-Fi/BT/GNSS/FM/LCD/Camera/Video/Audio/USB and so on., which are greater than “AP +standard Modem”. Finally, 5G S-Module Smart Type has flexible usage: it will simplify hardware design for complex systems, and Internet companies could develop and run Android APP by 5G S-Module Smart Type.

13.3.2 Connected Automotive

Connected automotive is a vertical service based on high-speed wide-area network, which is closely related to the development of 5G network. For example, autonomous driving requires a delay of less than 1ms, which falls within the requirement for 5G standards. The introduction of C-V2X technology provides the most important technical guarantee for the application of 5G in the automotive industry.

Automatic driving technology needs a large quantity of surrounding environmental data and information to make real-time decision. Sensors and the V2V and V2I communications are two main data resources. For guaranteeing the safe driving for automatic vehicles, it has higher requirement for the data transfer rate and stability. 5G network could provide more powerful networking capability, with the advantage of low latency, higher reliability and high bandwidth. The transfer rate will be over 2GB per second, so it is the technology and network base of guaranteeing automatic driving. 5G S-Module could be used for different devices in the automatic vehicles, such as video recorder, real time map, smart driving cockpit. The automotive grade 5G S-Module Smart Type can be applied using vehicle-mounted communication tools.

13.3.3 Connected Drones

A variety of practical applications of drones have been developed since drones were used for live broadcasting at the G20 summit in Hangzhou, China. The current application mainly focuses on the exploration and monitoring of public buildings and their surrounding environments. The application of 5G can significantly increase data transmission rate, enabling drones to detect and transmit more parameters of different types with less delay.

There are some required functions of the connected drones. It should be compatible with 4G and 5G network, and can switch seamlessly between 4G and 5G. It will have the relay function, and can relay Wi-Fi signals. It can have smooth handover between different base stations and can reconnect automatically when it drops from the network. It should have anti-interrupt function, and have strong signal stability. It will have high environment adaptability, and extreme environmental condition such as high temperature, low temperature and vibration will have no obvious impact on it. This raises very high requirement for the 5G S-Module Smart Type, which can be used in this application.

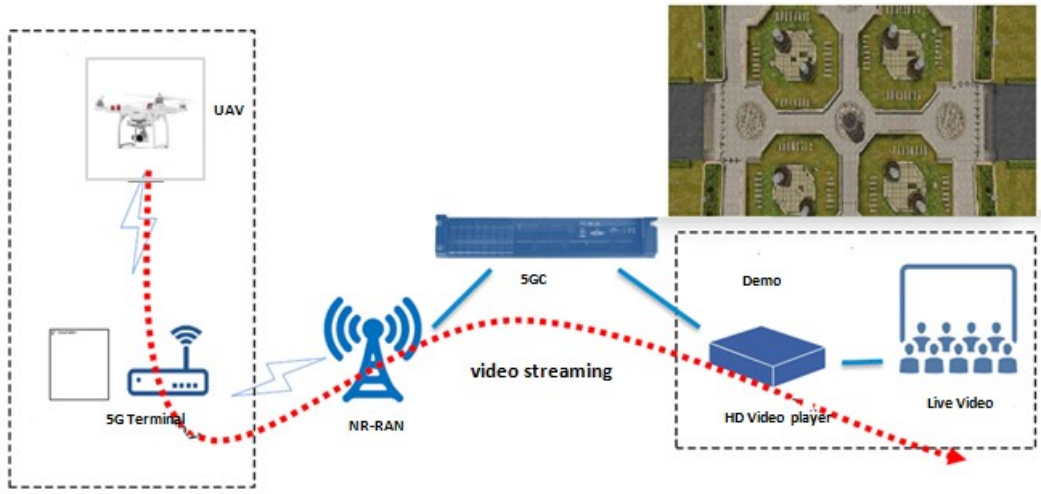


Figure 11-10 UAV Real time video live broadcasting

13.4 5G S-Module All-in-one Type-M and Type-L

13.4.1 USB Dongle

USB Dongle is a small device that plugs into a USB port on a host computer or host device to provide a connection to the cellular network. By attaching the dongle to the computer's USB port, Users could use USB dongle at home or at office without the guarantee of fixed internet access. Users can have a persistent internet connection to all workstations, because USB dongle allows for higher rates of utilization of the software.

USB dongles can be also used in the car system, which can be used seamlessly with user device, OS, and the car dash board, and can be used with Google map or other applications. When the car is equipped with USB dongle, it will be able to connect to the smart phone and other devices, and use the car built-in display screen and control key, and interact with the smart phone or other terminal. Users could make phone calls easily and safely, listen to the music, send and receive text message, use navigation, and much more.

USB dongle can also be used in remote medical systems. Since 5G guarantees the high data rate and low latency, the 5G USB dongle will be suitable to be applied in the medical systems for remote diagnosis and help the doctors to cure the patients remotely.

By using 5G S-Module All-in-one Type, 5G USB Dongle is expected to reduce system complexity and get to market faster.

Figure 11-11 USB dongle

Annex A 5G RF Component

Annex A.1 5G RF FEM Type1 (Separated n41 and n79)

Annex A.1.1 Diagram

- Separated n41 and n79 pin to pin 3x5mm modules
- Enables simultaneous 2 DL 2 UL supports in n41-n79
- Provides worldwide and regional coverage for initial 5G NR deployments

- Integrated high performance filter addressing co-existence requirements
- 4.5V ET/APT optimized
- PC2 for n41 and PC2 for n79
- Small solution size: 3x5 mm

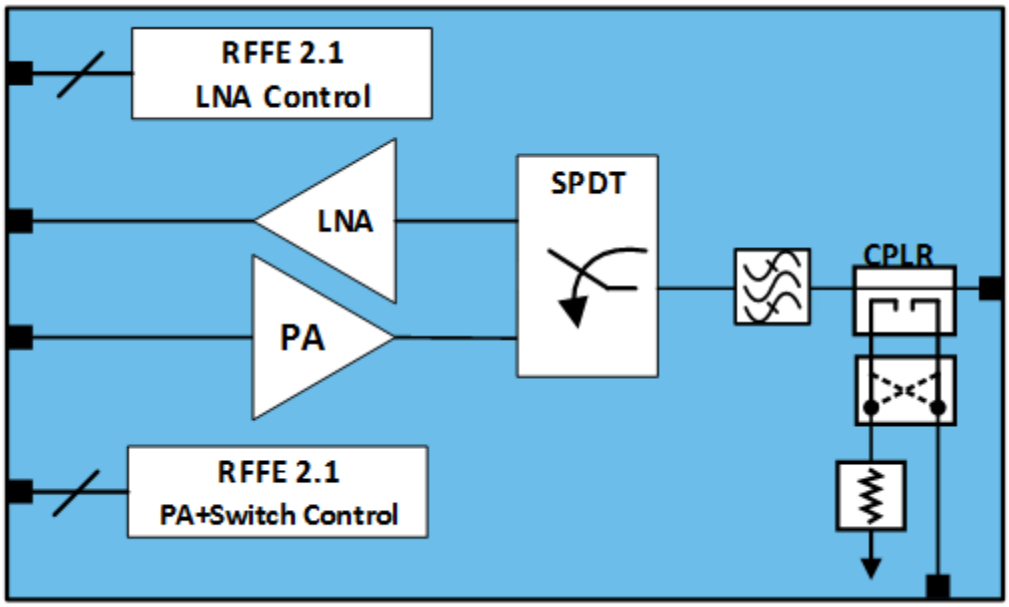


Figure A-1 Diagram

Annex A.1.2 Pin Layout

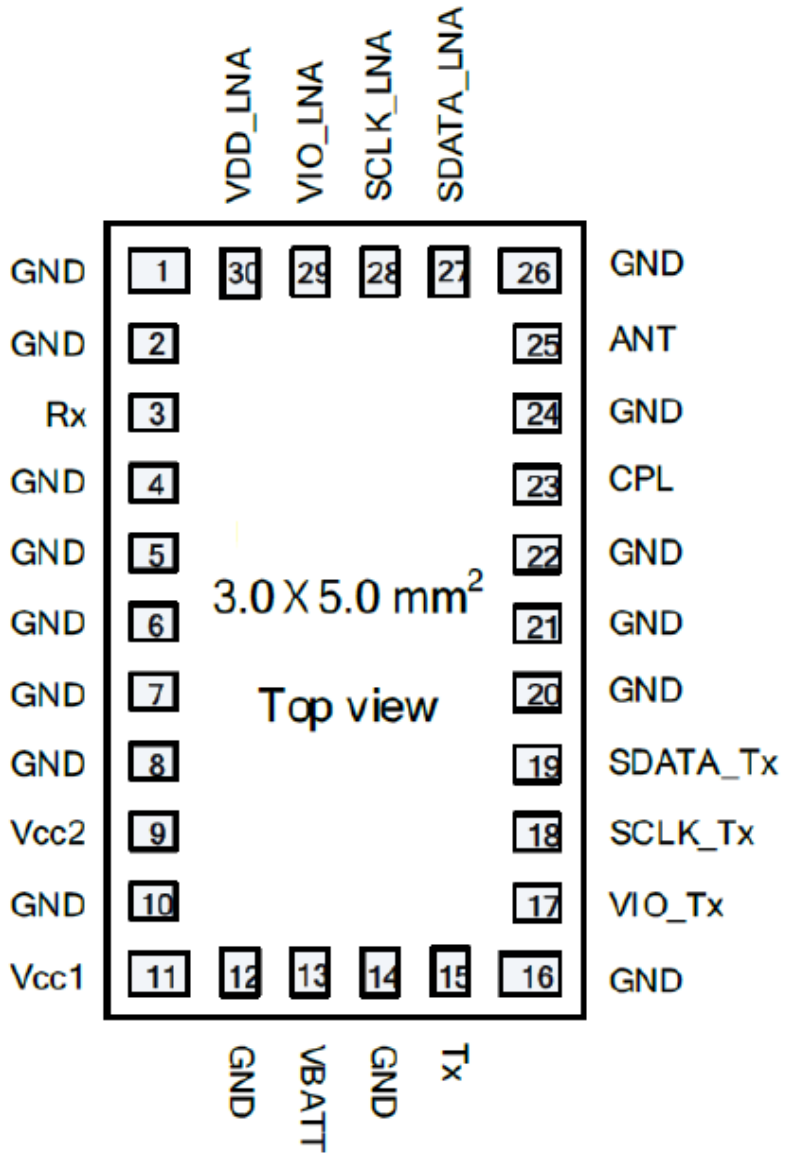


Figure A-2 Pin Layout

Annex A.1.3 Pin Size

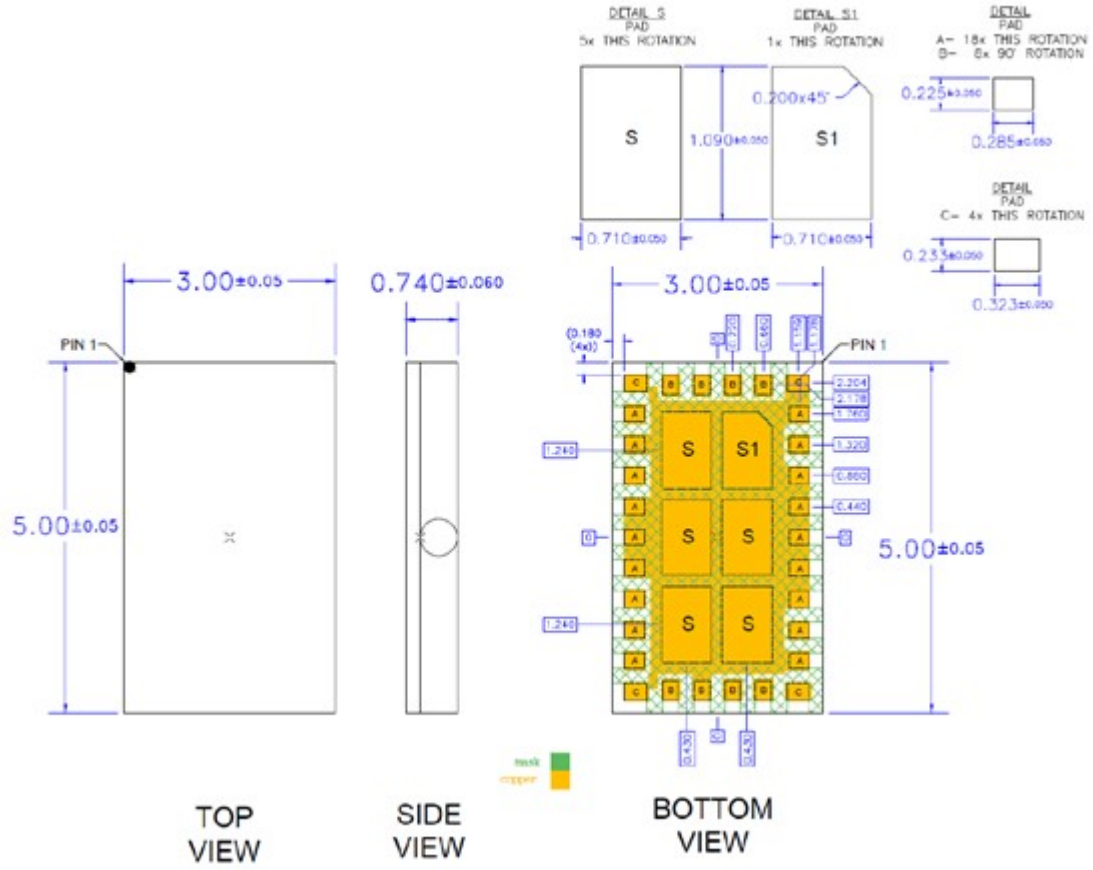


Figure A-3 Pin Size

Note: Above RF Module information and data in Clause A.1 are provided by Qorvo.

Annex A.2 5G RF FEM Type2 (n41)

Annex A.2.1 Diagram

- ET optimized, APT compatible PA's
- FDD Bands 1, 3, 4, 7, 66RX, 32SDL
- TDD Bands 34, 38, 39, 40, 41
- Small solution size: 6.5x8.6 mm

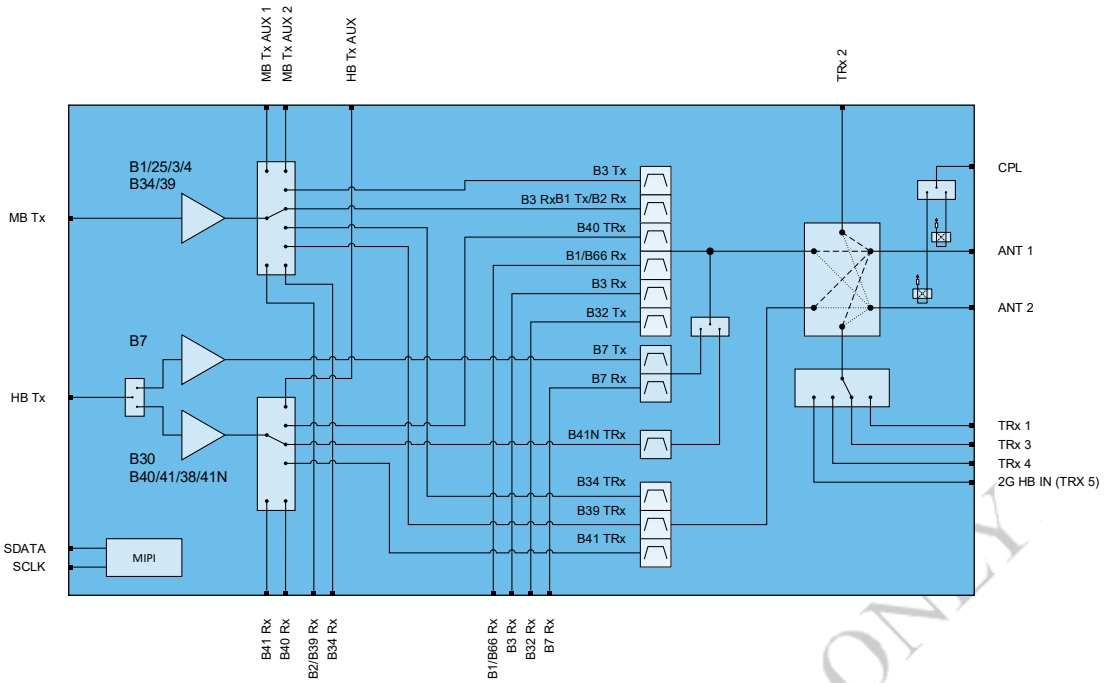


Figure A-4 Diagram

Annex A.2.2 Pin Layout

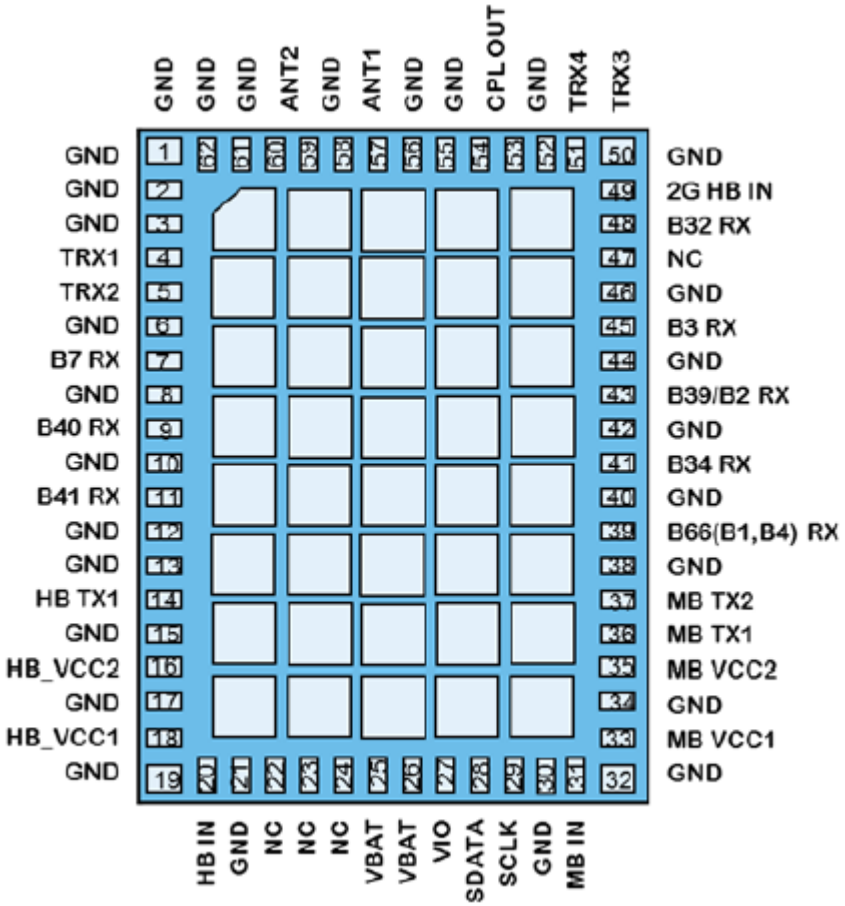


Figure A-5 Pin Layout

Annex A.2.3 Pin Size

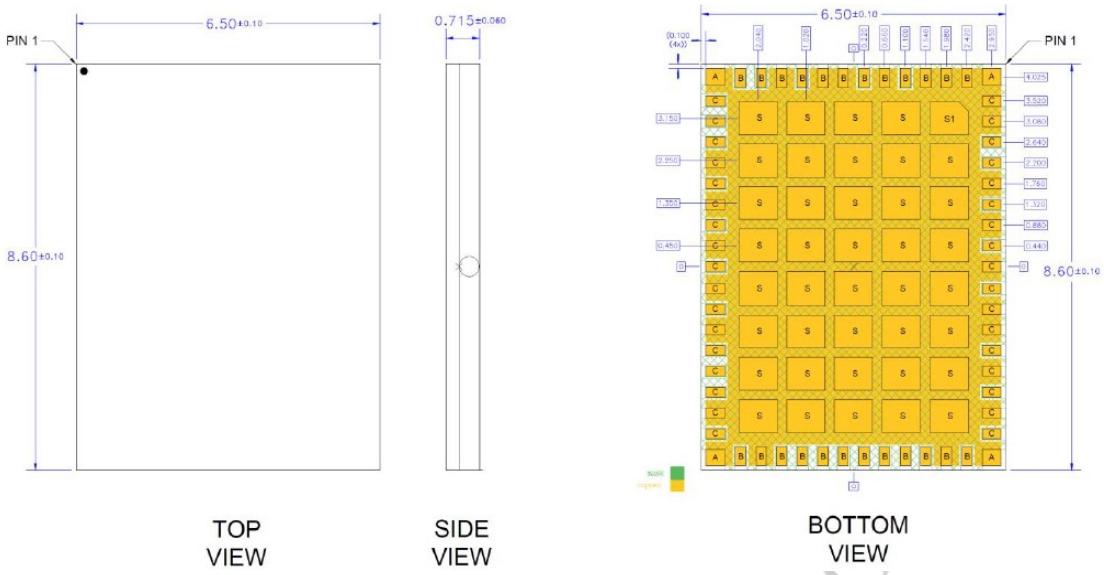


Figure A-6 Pin Size

Note: Above RF Module information and data in Clause A.4are provided by Qorvo.

Annex A.3 5G LTCC/SAW/FBAR Filters

As the detailed filter requirement and the background was discussed in another GTI report "GTI 5G Device RF Component Research Report", 5G filtering components would be required to cover much higher relative bandwidth ratio as opposed to current 4G requirement. Unlike the requirement for smartphones, the standard filter should be adopted for S-Module design as it has sufficient flexibility of adopting standardized filtering component. As shown in the following chart, at the present the technology of filters has been divided into 3 series: ONE is SAW technology, TWO is FBAR/BAW technology, THREE is LTCC or Multilayer Ceramic filter technology. It is capable of satisfying wider frequency bandwidth and higher frequency requirement. And this technology would be the choice for filtering components to be adopted for the S-Module design.

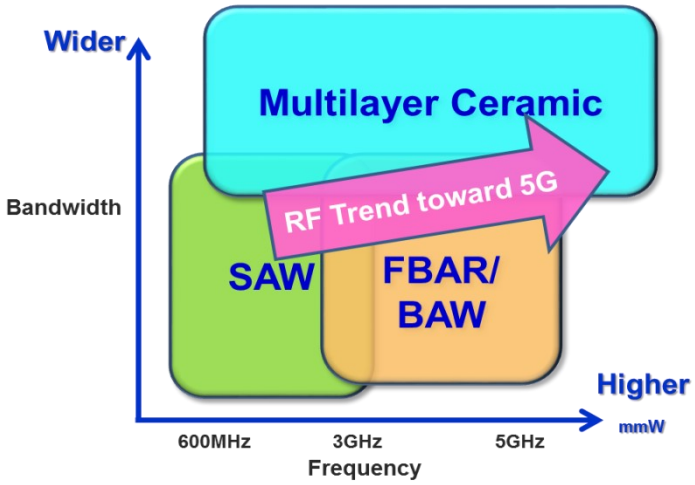


Figure A-7 Common Filter Technologies from Taiyo Yuden

With the utilization of multilayer ceramic technologies, it can provide extremely low insertion loss for Sub-6GHz while covering entire required bandwidth. The relative bandwidth that can be covered with multilayer ceramic filters is approximately from 5 to 50%. It also contributes to the downsizing and lower profile requirements with significantly stable performance and relatively low cost. This technology also provides rather higher power handling capabilities in comparison with SAW/BAW/FBAR technologies and this should be another advantage as HPUE has been required by 5G Sub-6GHz standard.

At the present, there are already solutions available supporting the HPUE compatible device incorporating Band n77, Band n78 and Band n79. Example of main performance of Band n79 filter is shown below.

Annex A.3.1 Diagram

Table A-1 Multilayer Ceramic Band Pass Filter for 5G NR Sub-6GHz Band n79 HPUE

Pass band Frequency	4.4GHz – 5.0GHz	
Insertion Loss (Typ)	0.55dB	
Attenuation (Typ)	2400-2500MHz	50.6dB
	2500-2690MHz	39.9dB
	8800-10000MHz	22.1dB
	13200-15000MHz	31.7dB
Power Capability	+33dBm at pass band frequency，10000Hr	
Size	2.0mm x 1.25mm x 0.65mm MAX，LGA Package	

Annex A.3.2 Pin Layout, Pin Size, Pin Definition

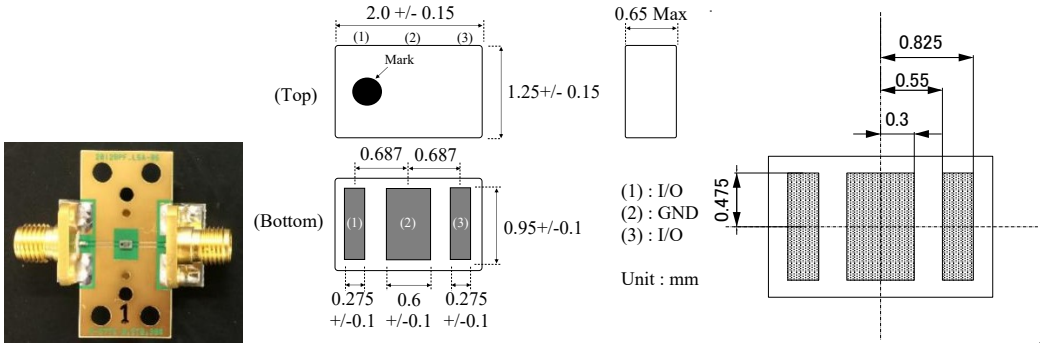


Figure A-8 Multilayer Ceramic Filter with its evaluation board (example photo), Dimension and footprint

Annex A.3.3 High power handling

Multilayer Ceramic Filter can survive +33dBm with over 10,000 hours due to the utilization of high quality inner electrode (including fine material and structure) which contributes to higher power durability while heat generation is minimized. (see reference test result)

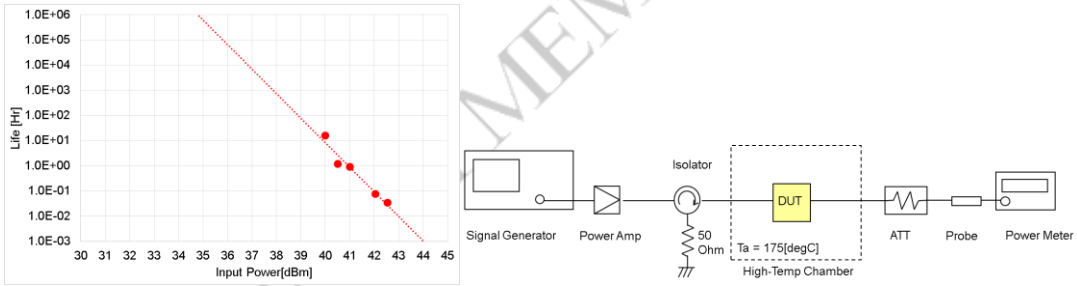


Figure A-9 Test result example of DUT: 2012 (EIA: 0805) size 3.5GHz BPF

Annex A.3.4 Structure and equivalent circuit

Utilization of distributed element filter:

Some resonators are structured in the filter. By increasing the number of resonators, wider bandwidth and steep cut-off can be realized. Distribution element system is mainly used for band pass filter including upcoming 5G NR Sub-6GHz requirement.

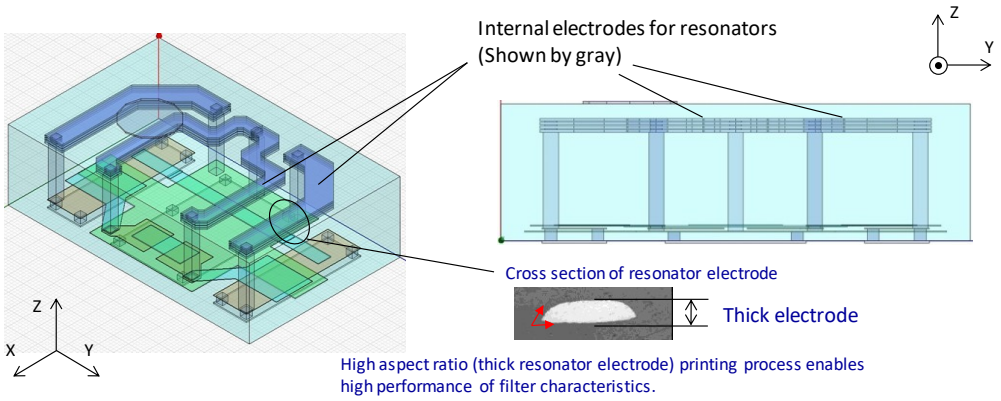


Figure A-10 Perspective View and side view of Distributed Element Filter

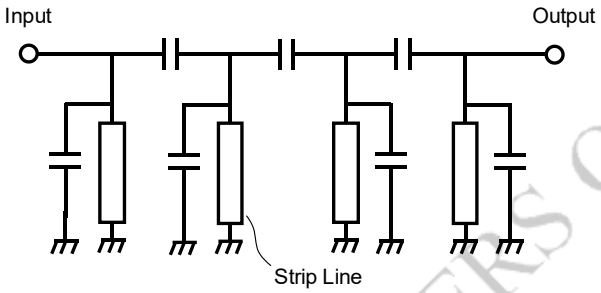


Figure A-11 Equivalent circuit of Distributed Element Filter

Annex A.3.5 SAW/FBAR Filter for Band n41

SAW/FBAR Filter Line-up for Band n41 in below table.

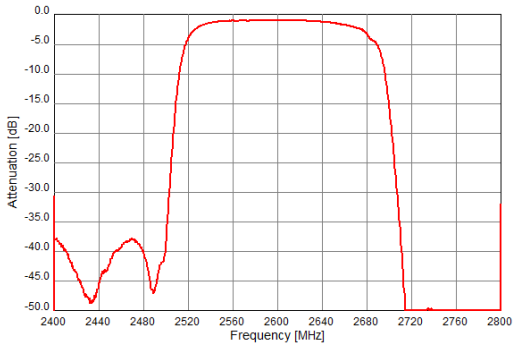
(These products had been originally developed for TD-LTE. Assuming these products can also be used for n41 while new conditions and/or requirements are under investigation.)

Table A-2 SAW/FBAR Filter for 5G NR n41 HPUE

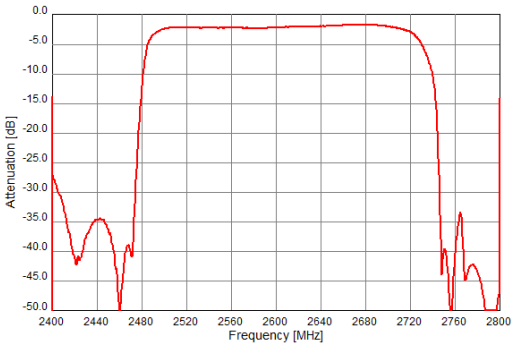
Status	Size	Frequency	Power Capability (TD-LTE)*
MP	1109	2535-2655MHz (BW: 120MHz)	+31dBm (2535-2655MHz) +32dBm (2575-2635MHz)
MP	1814	2496-2690MHz (BW : 194MHz)	+32dBm (2496-2690MHz)

*The power handling test condition for 5G NR (CBW: 100MHz) is under investigation.

2535-2655MHz (size: 1109)



2496-2690MHz (size: 1814)



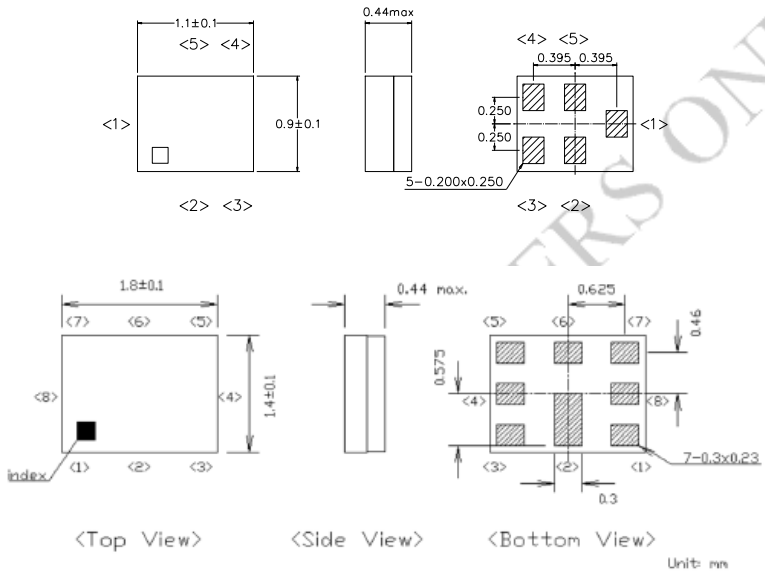


Figure A-12 Dimension for 1109 size and 1814 size SAW / FBAR Filters

Note: Above RF Filter information and data in Clause A.5 are provided by Taiyo Yuden.

Annex A.4 5G SAW Filters

Basically in the 5G era we can still use some of the SAW filters, including DPX, DRX, QPX, Tri-SAW filters, as we are using them now, such as n41(which should have the same frequency allocation with B41).

Annex A.4.1 Diagram

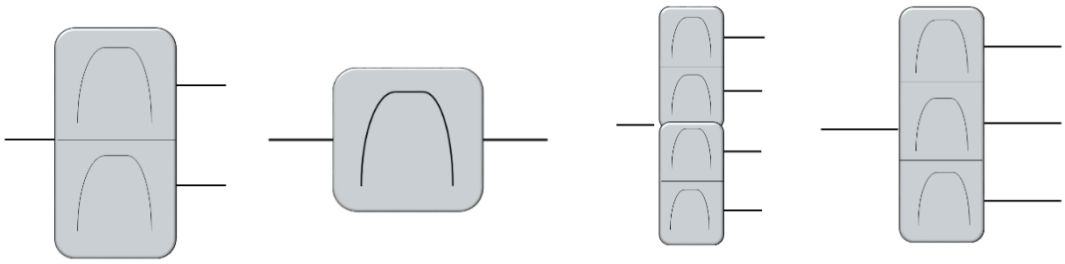


Figure A-13 Block Diagram of SAW Duplexer, SAW Filter, SAW QPX and SAW Tri-Filter

Annex A.4.2 Pin Layout

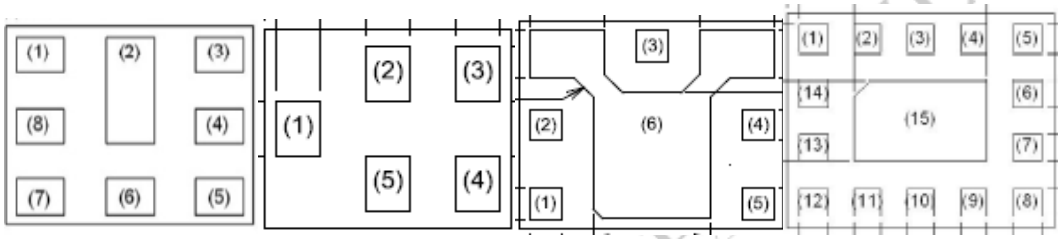


Figure A-14 Pin Layout of SAW Duplexer, SAW Filter, SAW QPX and SAW Tri-Filter

Please refer to the above figure of the pin layout of SAW Filters.

Annex A.4.3 Pin Size

The following illustration shows that under current situation 1814 sized SAW Duplexers have been designed with this kind of pin size. And this design may not be changed without any critical performance issues. Basically, the 1814 sized SAW Duplexers are designed with seven pins with the same size of 0.35mm×0.25mm and one bigger sized pin of 0.35mm×0.75mm.

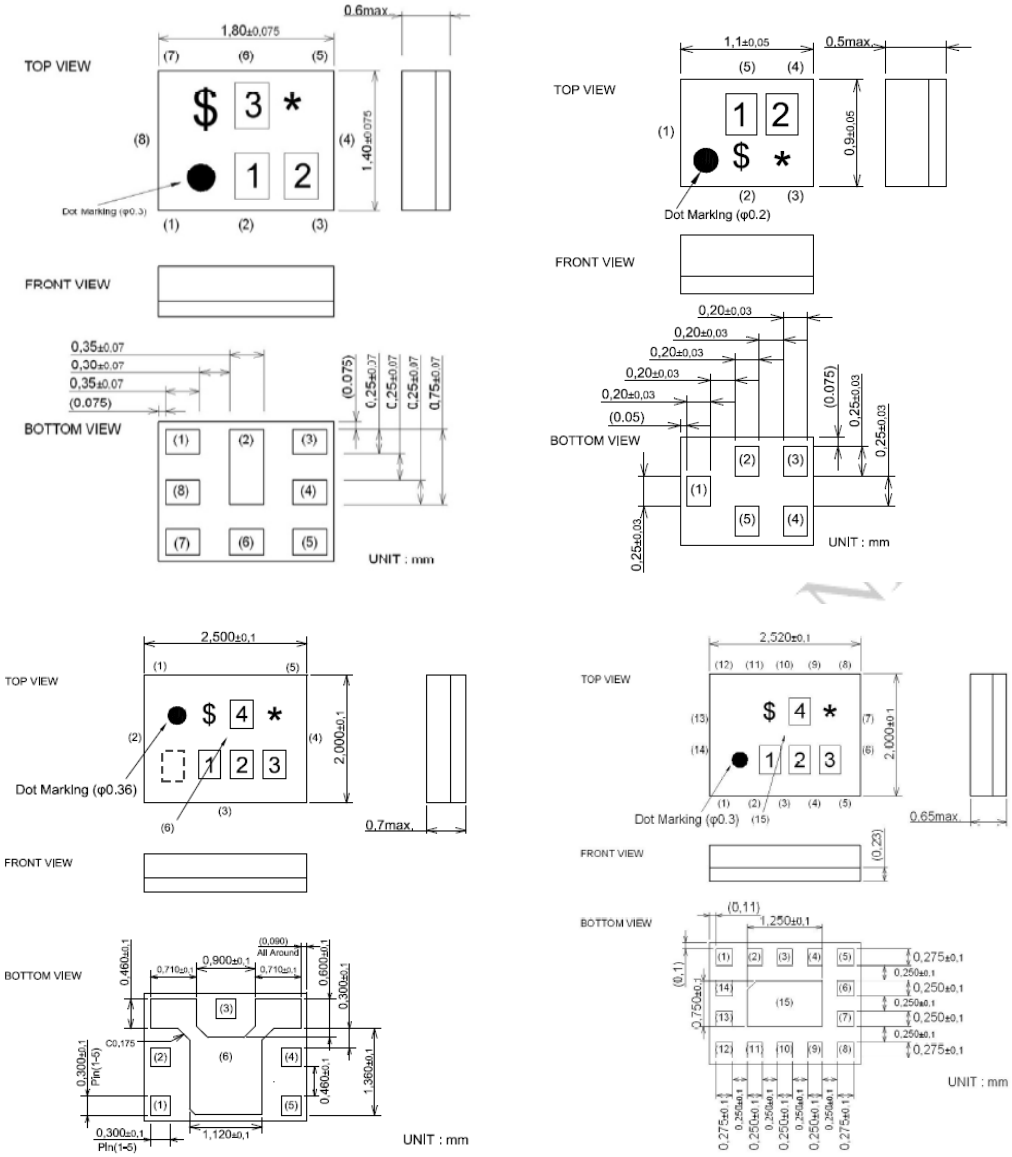
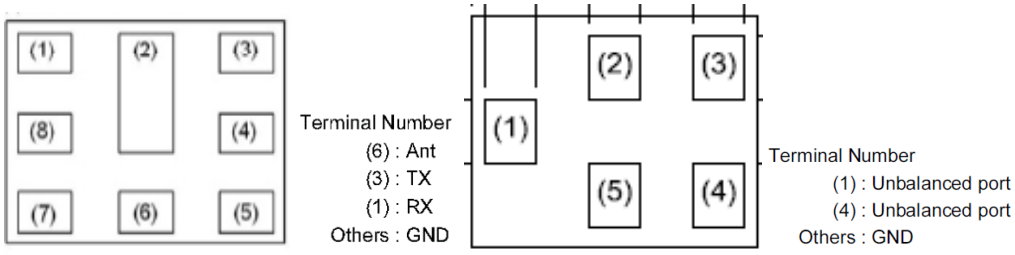


Figure A-15 Pin Size of 1814 SAW Duplexer, 1109 SAW Filter, 2520 SAW QPX and 2520 SAW Tri-Filter

Annex A.4.4 Pin Definition



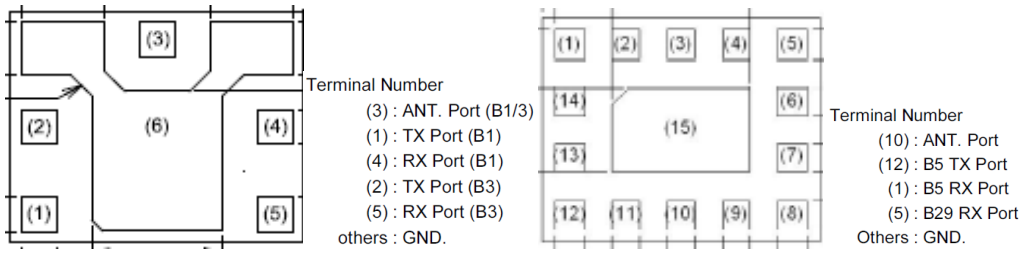


Figure A-16 Pin Definition of 1814 SAW Duplexer, 1109 SAW Filter, 2520 SAW QPX and 2520 SAW Tri-Filter

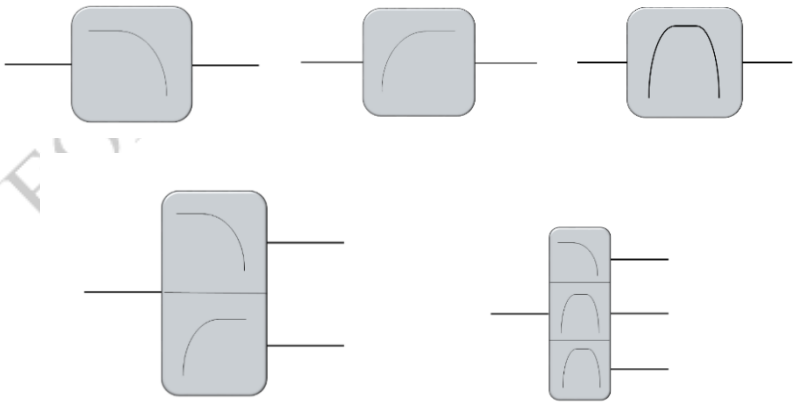
Note: Above RF Module information and data in Clause A.6 are provided by Murata.

Annex A.5 5G LTCC Components

Basically, in the 5G era we can still use some of the LTCC filters, including LPFs, HPFs, BPFs, Multiplexers, Baluns, and Couplers, as we are using them now. Based on the LTCC techniques, there will be various combinations of the LTCC components. Therefore, the below illustrations are just samples to let people know briefly about LTCC components.

As everyone knows that there will be various types of the LTCC components so that the pin layout of different LTCC components may be different as well, the following illustration is only a sample to show one of the possible layout structures of the LTCC components. To those who may concern about the applications of LTCC products, it should be noticed that the layout design, pin size, and pin definition of LTCC components should be including but not limited to the following design.

Annex A.5.1 Diagram



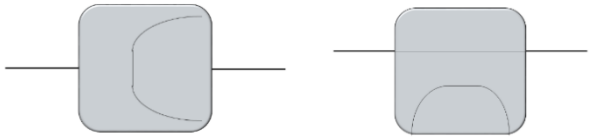


Figure A-17 Block Diagram of LPF, HPF, BPF, Diplexer, Triplexer, Balun and Coupler

Annex A.5.2 Pin Layout

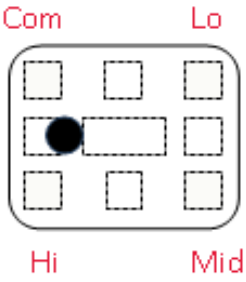
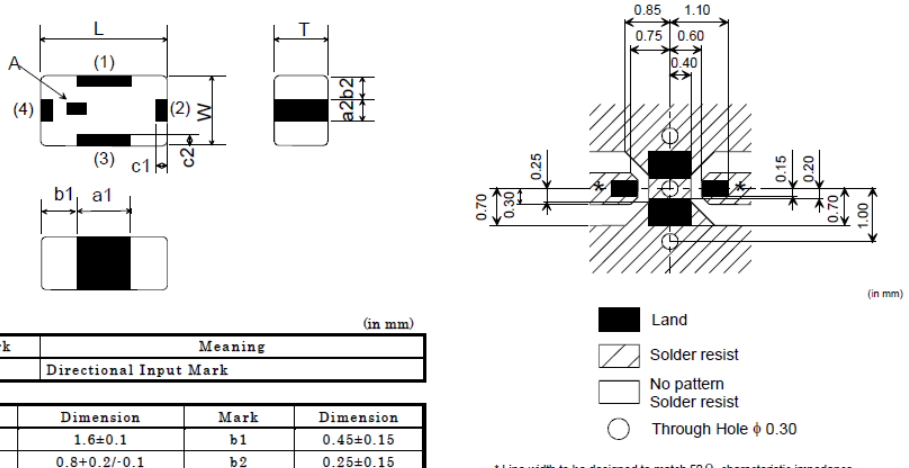


Figure A-18 Layout Illustration of LTCC Components

Annex A.5.3 Pin Size



(in mm)

Mark	Meaning
A	Directional Input Mark

Mark	Dimension	Mark	Dimension
L	1.6±0.1	b1	0.45±0.15
W	0.8+0.2/-0.1	b2	0.25±0.15
T	0.70 Max.	c1	0.20±0.15
a1	0.70±0.15	c2	0.20±0.15
a2	0.30+0.10/-0.15	-	-

Figure A-19 Pin Size Illustration of LTCC Components

Annex A.5.4 Pin Definition

TERMINAL CONFIGURATION

Terminal No.	Terminal Name	Terminal No.	Terminal Name
(1)	GND	(3)	GND
(2)	OUT	(4)	IN

Figure A-20 Pin Definition Illustration of LTCC Components

Note: Above RF Module information and data in Clause A.6 are provided by Murata.

Annex B Antenna for 5G S-Module

Annex B.1 Antennas for S-Module Basic Type

Annex B.1.1 Diagram

The module doesn't embed antennas itself. External antennas are required to apply in the products. The external antennas diagram is shown below.

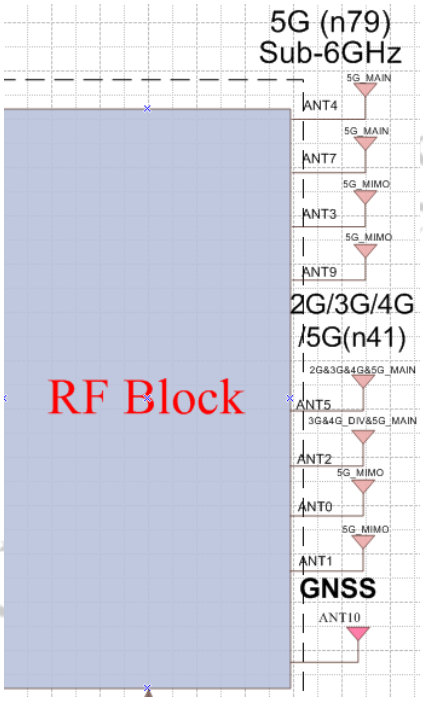


Figure B-1 Antenna Diagram

Annex B.1.2 Antennas connected to the module

Connections of antennas: IPEX connectors are built in the module, which are used to connect external antennas and module.

The information of antennas that are applied for the S-Module is shown in table B-1.

Table B-1 Antennas for S-Module Basic Type

Antenna	Bands	Antennas	Feature of Antennas	Description

Type		to Module		
4G/5G Antennas	5G NR Bands: Mandatory:n41 FDD-LTE Bands: Mandatory: B7, B3, B8, B25 Optional: B1, B4, B12, B17, B20 TDD-LTE Bands: Mandatory: B34, B39, B40, B41	AM47	5GNR(n41)&4G LTE main antenna	To get high data throughput for the products, 4 MIMO antenna design needs to use for 5G S-Module. For the compatibility of the network, 4G LTE antennas are still required.
		AG47	5GNR(n41) main antenna&4G LTE diversity antenna	
		AN39	5GNR(n41) MIMO antenna	
		AN43	5GNR(n41) MIMO antenna	
5G Antennas	5G NR Bands: Mandatory: n79	ANT4	5GNR(n79)main antenna	To get high data throughput for the products, 4 MIMO antenna design needs to use for 5G S-Module.
		ANT7	5GNR(n79) main antenna	
		ANT3	5GNR(n79) MIMO antenna	
		ANT9	5GNR(n79) MIMO antenna	
GNSS Antenna	GPS, BeiDou, GLONASS, or Galileo	ANT10	GNSS antenna	To meet the demand of precision positioning, GNSS antenna is applied

To achieve the designed performance of the module, the antennas of the products need to be customized. Suggested antenna performance will be shown in next section.

Annex B.1.3 Suggested antenna performance requirement

5G antennas

5G NR Bands:

Mandatory: n41, n79

The new radio (NR) equipment radio transmission and reception performance requirement should follow 3GPP specification TS 38.101-4 [5].

4G antennas

The test method shall be performed as defined by 3GPP TR36.978

FDD-LTE Bands:

Mandatory: B7, B3, B8, B25

Optional: B1, B4, B12, B17, B20

TDD-LTE Bands:

Mandatory: B34, B39, B40, B41

Equipment radio transmission and reception performance requirement should follow 3GPP specification #36.101

GNSS antenna

Antenna bandwidth: Return loss > 6dB (50 ohm) within working band (GPS, BeiDou, GLONASS, or Galileo)

Total efficiency: Total efficiency > -6 dB within antenna bandwidth

GNSS antenna radiated sensitivity (TIS): -145 dB

TTFF (Time to first fix): Max time < 18s

Annex B.2 Antenna for S-Module Smart Type

Annex B.2.1 Diagram

The module doesn't embed antennas itself. External antennas are required to apply in the products. The external antennas diagram is shown below.

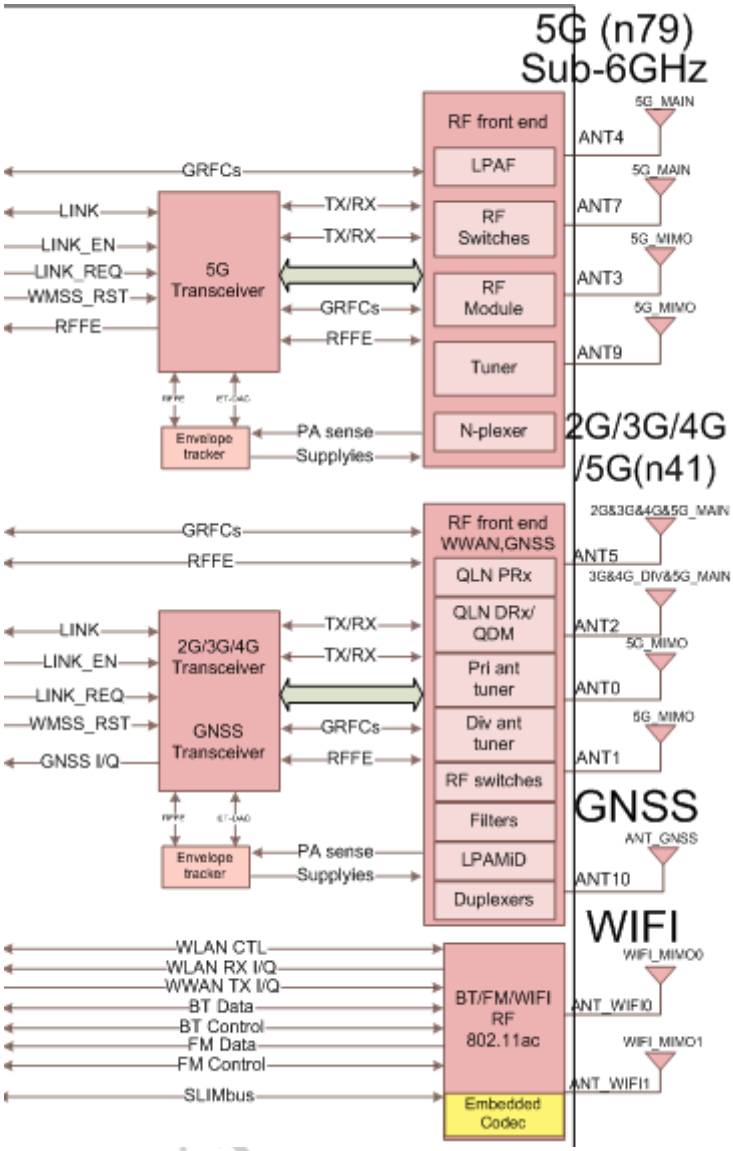


Figure B-2 Antenna Diagram

Annex B.2.2 Antennas connected to the module

Connections of antennas: IPEX connectors are built in the module，which are used to connect external antennas and module.

The information of antennas that are applied for the S-Module is shown in table B-2

Table B-2 Antennas for S-Module Smart type

Antenna Type	Bands	Antennas to Module	Feature of Antennas	Description

4G/5G Antennas	5G NR Bands: Mandatory:n41 FDD-LTE Bands: Mandatory: B7, B3, B8, B25 Optional: B1, B4, B12, B17, B20 TDD-LTE Bands: Mandatory: B34, B39, B40, B41	AM47	5GNR(n41)&4G LTE main antenna	To get high data throughput for the products, 4 MIMO antenna design needs to use for 5G S-Module. For the compatibility of the network, 4G LTE antennas are still required.
		AG47	5GNR(n41) main antenna&4G LTE diversity antenna	
		AN39	5GNR(n41) MIMO antenna	
		AN43	5GNR(n41) MIMO antenna	
5G Antennas	5G NR Bands: Mandatory: n79	ANT4	5GNR(n79)main antenna	To get high data throughput for the products, 4 MIMO antenna design needs to use for 5G S-Module.
		ANT7	5GNR(n79) main antenna	
		ANT3	5GNR(n79) MIMO antenna	
		ANT9	5GNR(n79) MIMO antenna	
GNSS Antenna	GPS, BeiDou, GLONASS, or Galileo	ANT10	GNSS antenna	To meet the demand of precision positioning, GNSS antenna is applied
Wi-Fi Antenna	2.4G, 5G	ANT_WI-FI0	Wi-Fi main antenna	2x2 Wi-Fi MIMO are applied
	2.4G, 5G	ANT_WI-FI1	Wi-Fi MIMO antenna	

To achieve the designed performance of the module, the antennas of the products need to be customized. Suggested antenna performance will be shown in next section

Annex B.2.3 Suggested antenna performance requirement

5G antennas

5G NR Bands:
Mandatory: n41, n79

The new radio (NR) equipment radio transmission and reception performance requirement should follow 3GPP specification #38.101-4

4G antennas

The test method shall be performed as defined by 3GPP TR36.978

FDD-LTE Bands:
Mandatory: B7, B3, B8, B25
Optional: B1, B4, B12, B17, B20

TDD-LTE Bands:
Mandatory: B34, B39, B40, B41

Equipment radio transmission and reception performance requirement should follow 3GPP specification #36.101

GNSS antenna

Antenna bandwidth: Return loss > 6dB (50 ohm) within working band (GPS, BeiDou, GLONASS, or Galileo)
Total efficiency: Total efficiency > -6 dB within Antenna Bandwidth
GNSS antenna radiated sensitivity (TIS): -145 dB
TTFF (Time to first fix): Max time < 18s

Wi-Fi Antennas

Antenna Band: 2.402 – 2483 GHz, & 4.910 – 5.835 GHz
Total efficiency: Total efficiency > -6 dB within Antenna Bandwidth

Annex C Sensor

Annex C.1 Sensor Technology

Sensor technology, computer technology and communication are three pillars of information technology. From the view of IoT, sensor technology measures the degree of information. Sensor technology is to get information from the nature, then use physical effect, chemical effect, and biological effect, and transfer the physical quantity, chemical quantity, and biological quantity into the quantity of electricity. Sensor uses numerous latest technologies from modern science and it is adopted by many industries.

The compositions of sensors are sensing element, transduction element, measurement, and conversion circuit.

There are three generations of sensor technology. The first-generation is structure type sensors, such as resistive sensor. The second-generation sensor is solid sensor, such as Thermocouple sensor, Hall sensor, etc. The third-generation sensor is smart sensor.

All sensors require accuracy, reliability, sensibility and stability. They need to be small size, fast response, easy to use and easy to adapt. And they should feature low cost and low power consumption.

The smart sensors use smart sensing technology to process signal. They should be self-calibrated, self-learning, self-adaptive and easy to combine with other AI technology.

The current study and development trend for the sensors are:

- Improve the sensors in automatic apparatus and robots;
- Develop new type sensors, such as non-contact temperature sensor for the PCB board, and ultrasonic sensor;
- Develop micro-assembly sensor system;
- Put more emphasis on data assembly, merge AI technology;
- Develop new effects, new materials, and new functions;
- The sensors will be more integrated, multi-functional and miniaturized;
- For the smart sensors, they will be digital, intelligent and networked;
- There are challenges in the undeveloped field, such as Bio-sensors.

Sensors are a kind of functional sub-modules, which can transfer external signals to electrical signals. They could be used inside or along with 5G S-Module for wide applications.

Annex C.2 Cutting-edge Sensor Application

Sensors have applications in many fields and have increased requirement in different areas. Here we introduce some cutting-edge development which may combine with the 5G S-Modules.

In the digital medical field, there are use cases like combined sensor for babies, continuous biosensor for the elderly and the test sensors inside human body for testing medicines. Such micro sensor has a tiny volume (1mmx1mmx0.45mm), and is implanted into the normal medicine. It is made of mini-silicon and tiny amount of Mg and Cu. When it is swallowed, it will create tiny voltage by gastric acid. Then there is a respondent apparatus outside human body and near the stomach. This apparatus gets the voltage signal and sensor transfers the data to the doctor's mobile phone. Thus, the doctor could monitor the patients on medicine, heart rate and body temperature.

STMicroelectronics developed an MEMS microphone, which could monitor the ultrasonic frequency spectrum in deep-layer, to detect pipeline leakage and other fault. This sensor is less than $1 and it can transfer the data stream to the microcontroller unit (MCU).

TDK's new magnetic sensor (TMR sensor) is a 360º sensor which could provide orientation with 0.2º, and is also less than $1. The new TAD2140 sensor could be used in the car steering wheel and windshield wiper and motor. It also could be used in the mobile handset for shockproof.

There is plastic sensor for amputation patients. The British company PST sensor has newest development on sensors which are integrated to soft plastic board. This innovation is for artificial limb. The sensor could report the temperature and moisture in the limb using Bluetooth. This sensor will be tested in the National Health Service in UK in fall of 2018.

There are sensors in IMU market. The French company Thales Group uses its newest NavChip2 to develop new market for its six axis IMU sensor. This sensor has 16G and velocity of 2,000 degree/second. It provides less than 5 degree/hour positioning drift, which is quite accurate. It could be used in cars, drones, and robots.

There is a sensor with low power. Rohm develops a micro contactless current sensor, which uses magnetic bias measurement to detect PCB current. This module is also less than $1. It has lowered the power consumption and heat dramatically.

Microchip Technology develops an enhanced capacitor contact sensor, which could be embedded into its new 32-bit MCU. This chipset is the first MCU which supports ARM TrustZone hardware safety technology. The contact sensor could get 4 signals in parallel and has better anti-noise and anti-moisture capability.

Japanese company Alps Electric developed different kinds of sensors. They can accurately detect changes in temperature, humidity, location, acceleration, light, and force. Alps will provide end-to-end IOT solutions with the sensors.

Annex C.3 The Universal Interfaces of Sensors

If we have to deploy 5G S-Module today with built-in sensor or connection to the sensor network, we may have to go with the UART, I2C and/or SPI interfaces since the available market-ready sensors do not support better designed I3C sensor interface. However, 5G S-Module is target for late 2019 deployment. That gives us some time to work with sensor component ecosystem to adopt the MIPI I3C interface.

The I3C combines features of I2C and SPI to provide a standard and scalable interface to connect multiple sensors with a low pin count and at low power. It is backward compatible with I2C, and allow I2C slave devices to exist on the same interface as other I3C devices. It provides in-band interrupts within the same I2C 2-wire interface.

The data rate supported on an I3C bus depends on the bus mode and device type. It can be from 8.8 to 26.7Mbit/s on a pure I3C bus. If the bus connects a mix of I2C and I3C devices, the I3C master can communicate to the I2C slaves at up to 400Kbit/s or 1 Mbit/s and to I3C slaves at up to 20.5Mbit/s.

A pure I3C bus supports sleep mode and connects a dozen devices.

An example block diagram of I3C interconnections is shown in Figure 8-9. There are devices with Master role, devices with an I3C Slave role, and devices with an I2C Slave role. Note that I3C Secondary Master Devices are capable of both Master and Slave roles at different times.

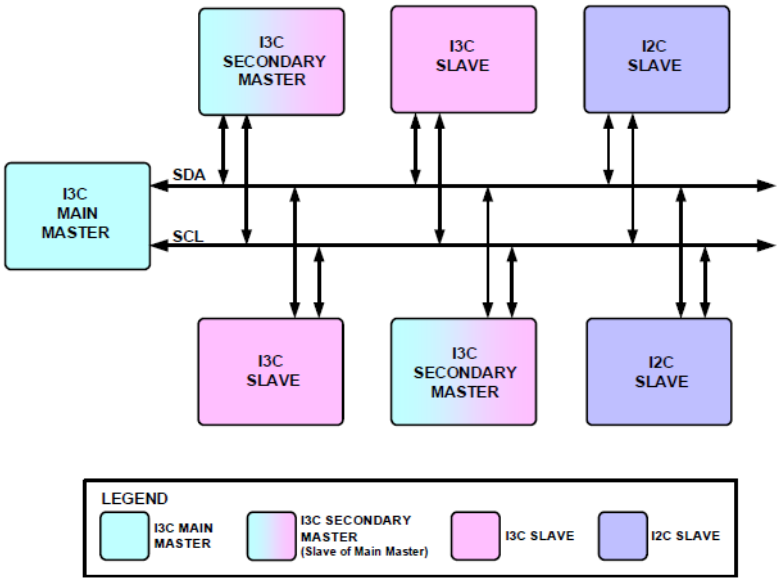


Figure C-1 I3C Bus with I2C Devices and I3C Devices (Source: MIPI)

To meet the requirement of different vertical industry application, it is best to have S-Module with built-in dual-role (master and slave) I3C capability.