RM530N-GL

LP(545) mmWave Antenna Design Guide

5G Module Series

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Safety Information

The following safety precautions must be observed during all phases of operation, such as usage, service or repair of any cellular terminal or mobile incorporating the module. Manufacturers of the cellular terminal should notify users and operating personnel of the following safety information by incorporating these guidelines into all manuals of the product. Otherwise, Quectel assumes no liability for customers' failure to comply with these precautions.

Full attention must be paid to driving at all times in order to reduce the risk of an accident. Using a mobile while driving (even with a handsfree kit) causes distraction and can lead to an accident. Please comply with laws and regulations restricting the use of wireless devices while driving.

Switch off the cellular terminal or mobile before boarding an aircraft. The operation of wireless appliances in an aircraft is forbidden to prevent interference with communication systems. If there is an Airplane Mode, it should be enabled prior to boarding an aircraft. Please consult the airline staff for more restrictions on the use of wireless devices on an aircraft.

Wireless devices may cause interference on sensitive medical equipment, so please be aware of the restrictions on the use of wireless devices when in hospitals, clinics or other healthcare facilities.

Cellular terminals or mobiles operating over radio signal and cellular network cannot be guaranteed to connect in certain conditions, such as when the mobile bill is unpaid or the (U)SIM card is invalid. When emergency help is needed in such conditions, use emergency call if the device supports it. In order to make or receive a call, the cellular terminal or mobile must be switched on in a service area with adequate cellular signal strength. In an emergency, the device with emergency call function cannot be used as the only contact method considering network connection cannot be guaranteed under all circumstances.

The cellular terminal or mobile contains a transceiver. When it is ON, it receives and transmits radio frequency signals. RF interference can occur if it is used close to TV sets, radios, computers or other electric equipment.

In locations with explosive or potentially explosive atmospheres, obey all posted signs and turn off wireless devices such as mobile phone or other cellular terminals. Areas with explosive or potentially explosive atmospheres include fuelling areas, below decks on boats, fuel or chemical transfer or storage facilities, and areas where the air contains chemicals or particles such as grain, dust or metal powders.

About the Document

Revision History

Version	Date	Author	Description
-	2022-01-25	Jumping HE	Creation of the document
1.0	2023-01-18	Summer SUN	First official release
1.1	2023-04-18	Summer SUN	1. Updated the parameter of modulation and carrier aggregation and deleted information about bandwidth (Table 2). 2. Updated the antenna module placement reference (Figure 5).

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1 Introduction

This document mainly provides antenna design guidelines for mmWave design of Quectel RM530N-GL module using QTM545 mmWave antenna.

It helps you quickly understand QTM545 application scenarios, interface specifications, electrical and mechanical details, and design-related information. This guide facilitates the use of RM530N-GL with QTM545 to set up mmWave handheld high net speed applications such as laptop, tablet, game station, video monitor, virtual reality device etc.

1.1. Upgrades of QTM545

QTM545 mmWave antenna module, upgraded from QTM525, supports two bands (28 GHz and 39 GHz) with 32 dBm EIRP enhancement to help you simplify the design. QTM545 is now available in only one variant, supporting n257, n258, n260, n261 and measuring 23.8 mm × 3.5 mm × 2.14 mm.

Table 1: Comparison Between QTM525 and QTM545

Parameters	QTM525	QTM545
Size (mm)	23 × 4.2 × 1.94	23.8 × 3.5 × 2.14
Bands	QTM525-2: n257/258/261 QTM525-5: n257/n258/n260/n261	n257/n258/n260/n261
IF connector vendor	IPEX	Panasonic
IF Loss @ highest freq (dB)	6.8	8.8
Antenna element number	4	5
Power consumption (W)	Module: 0.2 (PMIC) + 1.28 (RFIC)	Module: 0.4 (PMIC) + 1.7 (RFIC)
EIRP (dBm)	< 30	30.7 (n258), 31.8 (n257/n261), 30.5 (n260)
DL Bandwidth (100 MHz)	8CC	8CC (4CC for RM530N-GL)

QTM545 package drawing is as follows:

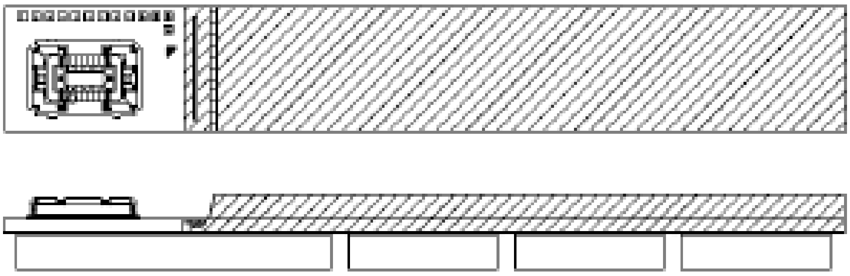

Figure 1: QTM545 Package Drawing

1.2. Functional Diagram

The following figure shows a functional diagram of the QTM545 module and illustrates its major functional components.

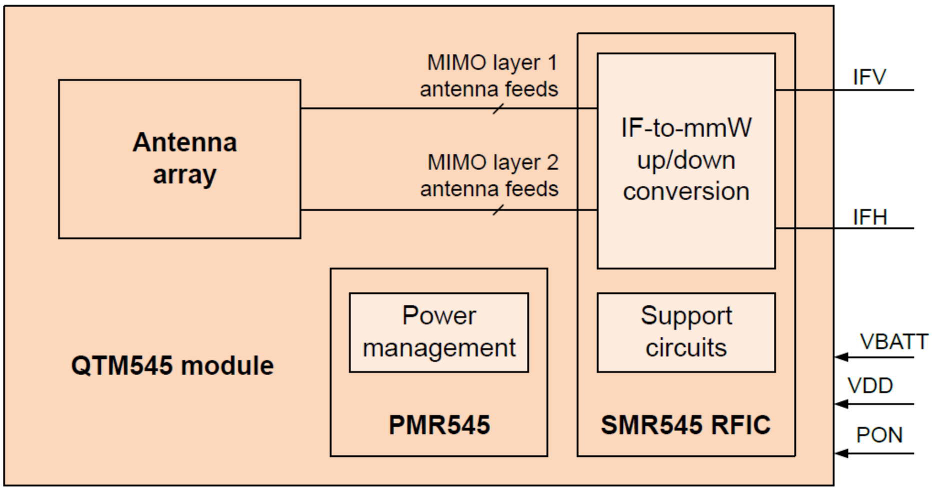

Figure 2: Functional Diagram of QTM545 Module

1. SMR545 RFIC:
   - Provides IF-to-mmWave (Tx) and mmWave-to-IF (Rx) frequency conversion (uplink/downlink converter).
   - Provides amplitude weighting and phase shifting to facilitate RF beam forming.
   - Provides the combiner/splitter, switch, filter to multiplex the IF signal.

2. PMR545: Provides all other RFIC power supplies.

3. Antenna array: Provides five pairs of dual-frequency patches to emit the electromagnetic wave.

4. Interfaces:
   - The IFV/IFH signals are multiplexed with local oscillator (LO) signals and beam steering signals, and have a frequency range of 10 MHz to 13 GHz.
   - Provides power supplies VBATT (3.7 V nominal) and VDD (1.9 V nominal) for the QTM545 module.
   - Provides input signal PON (1.8 V nominal) from RM530N-GL to enable the PMR545 PMIC.

1.3. Key Features

The following table describes detailed features of QTM545.

Table 2: Key Features

Features	Details
Power of modem	● Max. power supply:4.75 W (full UL with 4CC 2 × 2 MIMO maximum power) ● Typ. power supply: 2.1 W (full DL with 1CC 2 × 2 MIMO uplink)
3GPP 5G NR	Third-generation board supporting 5G NR FR2 in Rel-16
Frequency bands	n257, n258, n260 and n261
MIMO	Dual-polarization MIMO (horizontal and vertical)
Modulation	● DL: 64QAM ● UL: 64QAM
Carrier aggregation	● DL 2 × 2 MIMO: up to 4CC (100 MHz) ● UL 2 × 2 MIMO: up to 2CC (100 MHz)
IF connector	● Panasonic MCN AXG4B0612DJ2 (receptacle mounted on QTM545)
Transmitter paths	● Each transmitter chain provides amplitude weighting, phase shifting, and I/Q quadrature IF-to-mmWave frequency conversion
Transmit power detectors	● Power detector to sense the forward power of each transmission path ● Used for maximum transmit power limit and factory power calibration
Receiver paths	● Each receiver chain provides amplitude weighting, phase shifting, and I/Q quadrature mmWave-to-IF frequency conversion
Digital control interfaces	● SMR545 beam steering signal provided by IF signal traces ● PON input signal to enable the PMR545 PMIC
Operating voltages	● Two external supply voltages: VBATT_3.7 V and VDD_1.9 V nominal

2 Product Overview

2.1. Pin Assignments

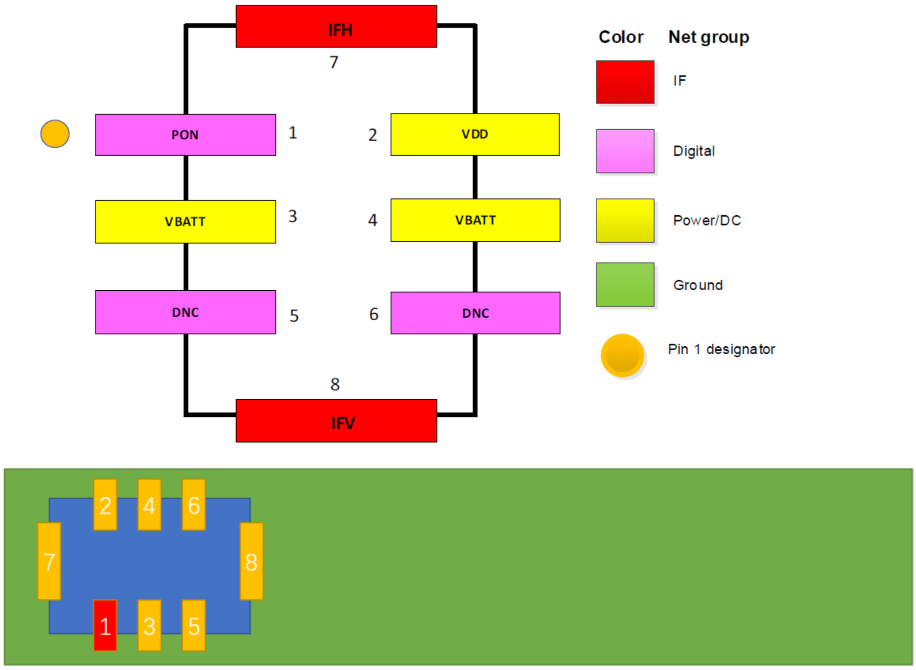

Figure 3: Pin Assignments on QTM545 Module (Top View)

The shield of connector is grounded and not shown in the figure above.

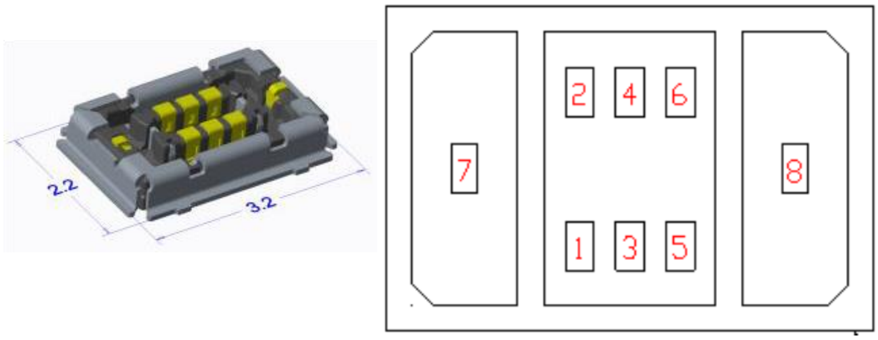

Figure 4: Physical Connector with Pin Assignment on QTM545 Module

The physical connector of QTM545 module is AXG4B0612DJ2 from Panasonic.

Table 3: Pin Definition of QTM545

Pin Name	Pin No.	Description
IFH	7	IF for horizontal signal with beam steering (10 MHz–13 GHz)
IFV	8	IF for vertical signal with LO signal (10 MHz–13 GHz)
PON	1	Enable the input signal from RM530N-GL module to PMR545 in QTM545
VBATT	3, 4	3.7 V nominal power supplied by the motherboard
VDD	2	1.9 V nominal power supplied by the motherboard
DNC	5, 6	Don't connect it externally

2.2. Electrical Specifications

Table 4: Operating Conditions

Parameter	Description	Min	Typ.	Max	Unit
Power-supply Voltages					
VBATT	Power for PMR545, 3.7 V nominal power supply	2.5	3.7	4.8	V
VDD	Power for analog and digital	1.85	1.904	2.04	V

	circuits,1.9 V nominal power supply				
Thermal Conditions					
T	Device operating temperature	Ta = -30	-	Tj = 85	°C

NOTE

Design requirements from the vendor for possible future upgrade:

1. VBATT: 1900 mA max (950 mA per pin) at VBATT = 2.5 V.
2. VDD: 200 mA max per pin.

Table 5: Digital IO Characteristics

Parameter	Description	Min	Typ.	Max	Unit
V_{IH}	High-level input voltage	0.65 × V_{IO}	-	V_{IO} + 0.3	V
V_{IL}	Low-level input voltage	-0.3	-	0.65 × V_{IO}	V
V_{HYS}	Schmitt hysteresis voltage	15	-	-	mV
I_{IL}	Input leakage current	-400	-	400	nA
C_{IN-D}	Input capacitance, digital input	-	-	20	pF

NOTE

V_{IO} is 1.8 V (nominal voltage).

3 Antenna Design Guidelines

3.1. Antenna Module Placement

QTM545 is paired with RM530N-GL to provide the 5G mmWave service as the following figure:

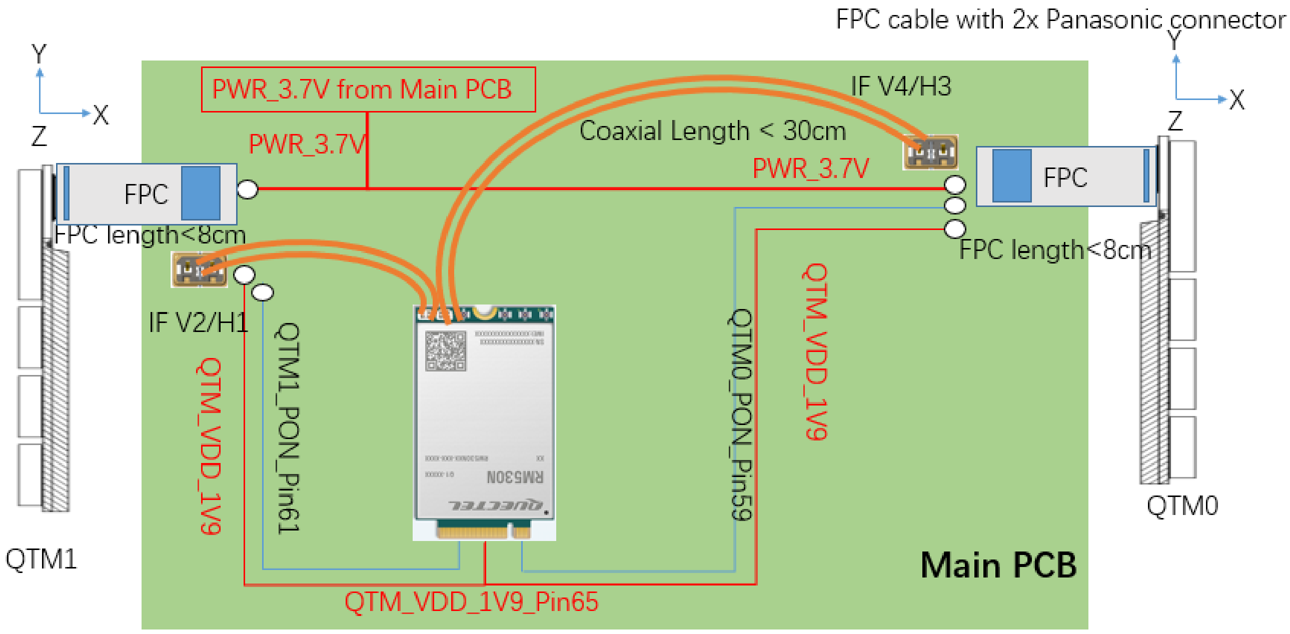

Figure 5: Antenna Module Placement Reference (RM530N-GL + 2 × QTM545)

The connector type on the RM530N-GL is 818025398 from ECT, and requires an FPC as a connector adaptor. Coaxial cables are used to extends the IF transmission distance.

NOTE

Please note that the connector on the RM530N-GL is coaxial cable connector for reducing IF path loss, which is different from that of QTM545.

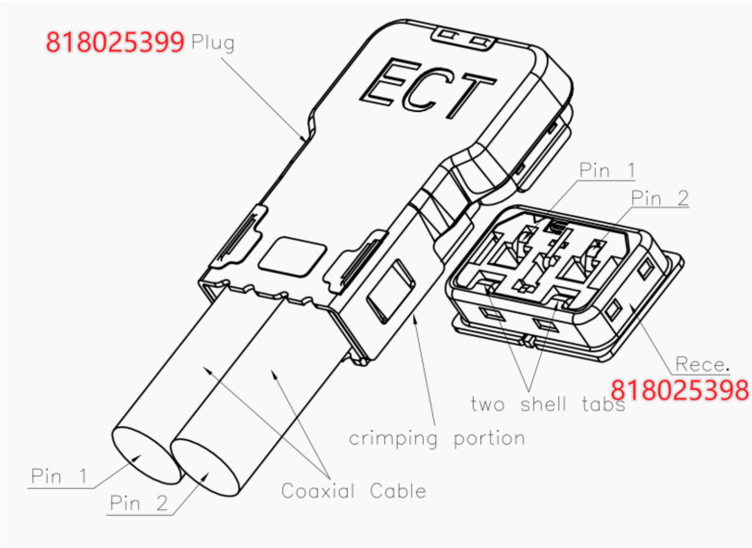

Figure 6: Physical Connector of 818025398 from ECT on RM530N-GL

3.2. FPC Design

QTM545 cannot be directly connected to RM530N-GL. Therefore, it is necessary to use an FPC connector adapter for the connection.

RM530N-GL uses the coaxial cable to extend the distance between QTM545 and itself, and the cable is 1.13 mm OD from ECT.

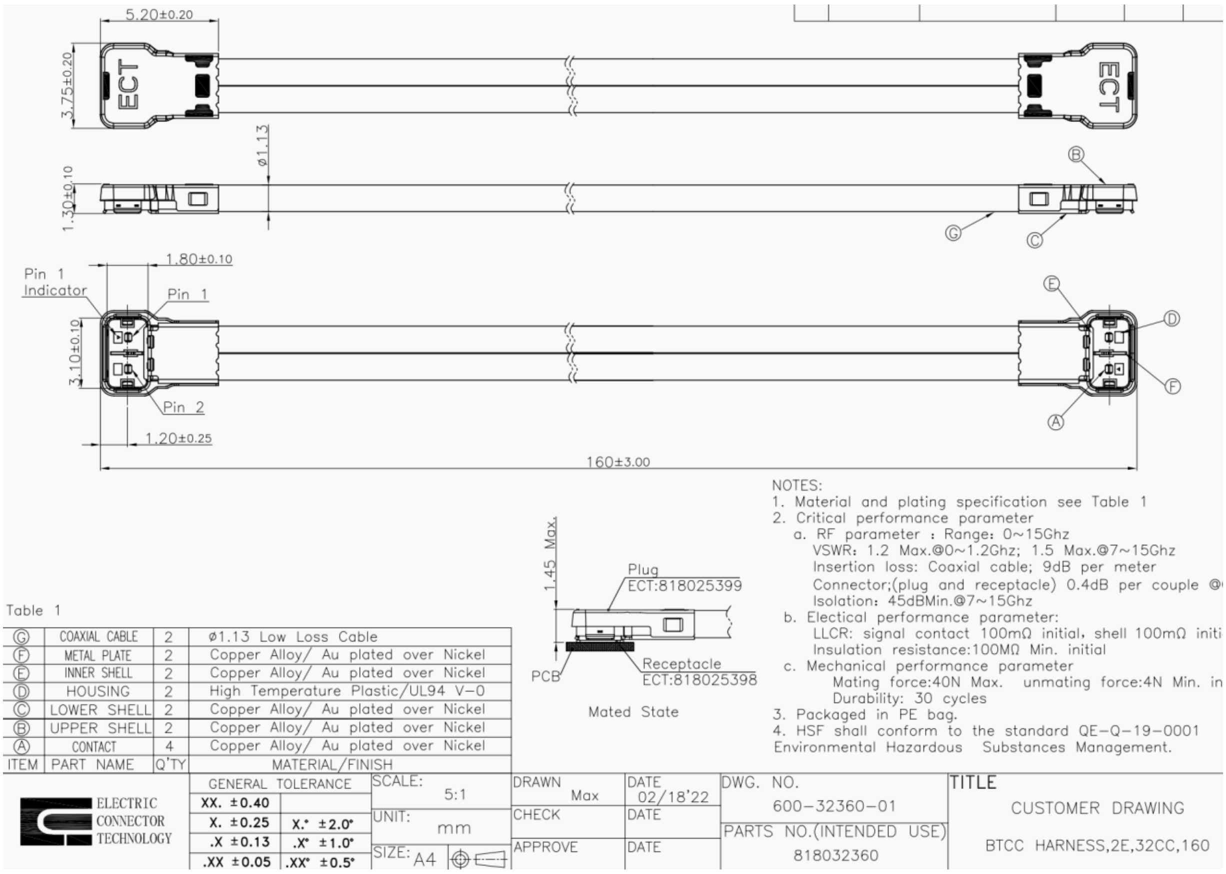

Figure 7: 1.13 mm OD Coaxial Cable

You could use the following connector on the FPC adaptor and motherboard. For more details about the connection diagram, see ***Figure 5***.

Table 6: Connector Examples on 5G mmWave Frame Using RM530N-GL with QTM545

Vendor	Cable	Connector type
ECT	Coaxial Connector	2 × 818025399 (plug) on Coaxial cable 1 × 818025398 (receptacle) on RM530N-GL
Panasonic	FPC Connector	1 × AXG4B0612DJ2 (receptacle) on QTM545 2 × AXG3B0612DJ2 (plug) on FPC

The following figure shows the reference stack-up of FPC.

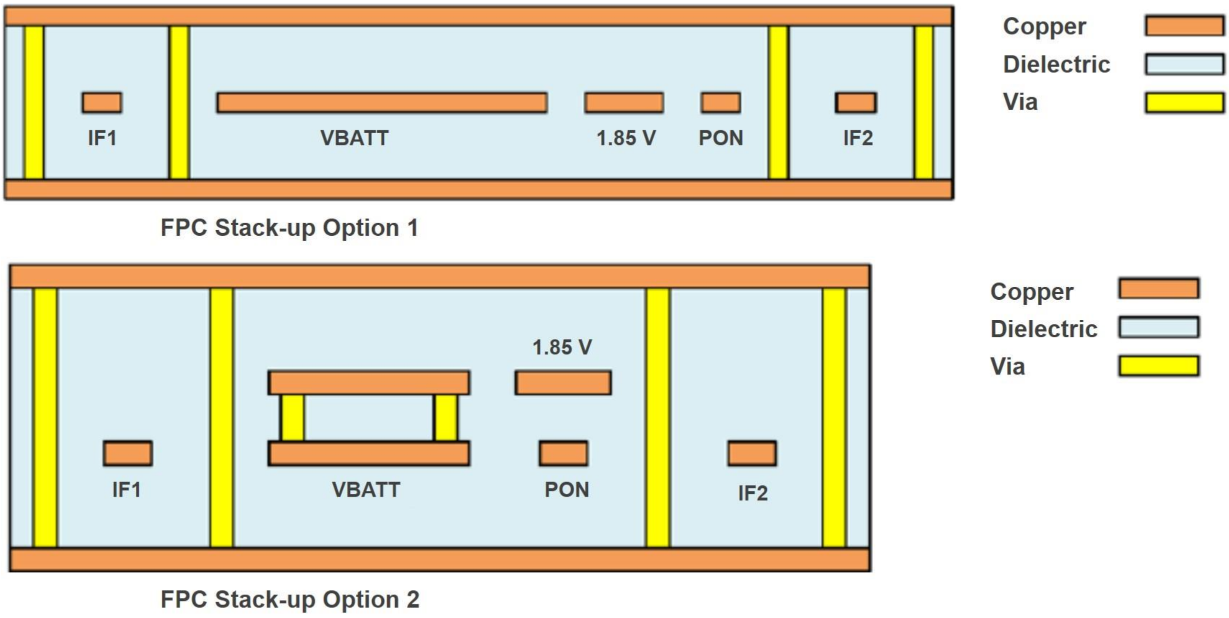

Figure 8: FPC Stack-up Recommendation

- FPC cable manufacturer recommendation: Forwin, Sunway, ECT, Daeduck, Career, Mutual-Tek, Teracomm, Kinwong, and Mektec.
- For 7–13 GHz frequency range, the maximum insertion loss on IF path should not exceed 7.0 dB (The total insertion loss requirement is 8.8 dB, therein 1.8 dB is reserved for the RM530N-GL).
- The formulation is:
  IF path insertion loss = coaxial cable loss + connector loss + motherboard PCB trace loss with via + connector loss + FPC trace loss with via.

Table 7: Example of Insertion Loss

Cable with PCB	IL (Insertion Loss)
2.1 (300 mm coaxial cable) + 0.2 (connectors) + 0.6 (15 mm trace on motherboard) + 2 × 0.15 (via on motherboard) + 0.2 (connectors) + 3.2 (80 mm trace on FPC) + 2 × 0.15 (via on FPC)	6.9 dB

NOTE

1. Coaxial Cable IL ≈ 2.1 dB/ 300 mm; Coaxial mated connectors IL ≈ 0.2 dB.
2. Trace loss on PCB ≈ 0.04 dB/mm; Via loss in PCB ≈ 0.15 dB.
3. You can reduce the trace length or coaxial length according to the actual design for better IL reduction.

3.3. Thermal Design and Power Consumption

It is important to have adequate thermal transfer design to transfer heat from the backside of the QTM545 (opposite the antenna elements) to the device midframe to keep the QTM545 within its thermal operating limit.

3.3.1. Thermal Limit Value

Table 8: Thermal Limit Value of QTM545 Module

Parameter	Typical Value	Unit	Description
Tj	85	°C	QTM545 semiconductor thermal limit
Tc	40 for metal cover	°C	QTM545 module case thermal limit
	45 for plastic cover	°C	

The average power dissipation of QTM545 module = 1.76 W: 0.4 W(PMIC) + 1.7 W(RFIC) × 0.8 (peak power 1.7 W).

NOTE

1. Ta is the temperature of the surrounding environment (typically air) of the device under test.
2. Tj is the maximum allowable temperature of the silicon in an Integrated Circuit.
3. Tc is the maximum allowable temperature of the antenna module case.

3.3.2. Recommended Design

The recommended designs for QTM 545 module thermal transfer are as follows:

1. Use one external thermistor for each QTM545 module optionally. The thermistor should be placed close to the corresponding antenna module, so the thermistor reading correlates well with the Tc hotspot caused by QTM545 module.

2. Use a gel/grease type TIM to fill in the air gap between the module and a heatsink.

3. Recommended gel/grease type TIM vendors:
   - Parker Chomerics GEL 30: 3.5 W/(m·K) thermal conductivity, soft, and compliant with low required compressive force.
   - Shin-Etsu-X-23-7868-2D: 6.2 W/(m·K) thermal conductivity, highest thermal conductivity or X-23-8117-6.0 W/(m·K) thermal conductivity, pump-out resistant due to high viscosity.

4. Metal heatsinks: Aluminum 6063-T5 with surface treatment, such as nano carbon coating, to enhance thermal radiation under natural convection heat transfer. The dimension drawing of the heatsink with sufficient cooling capacity is as follows.

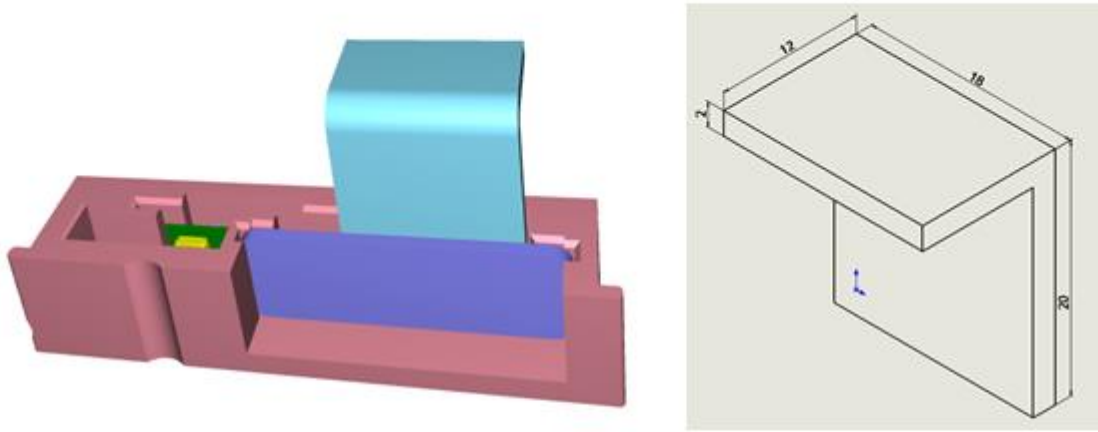

Figure 9: Heatsink Mounted with QTM545 Module and Antenna Radome (Unit: mm)

3.3.3. Power Consumption

The antenna module also requires sufficient power, and the thermal design should be implemented when the antenna module is in a steady state. Otherwise, the performance will be limited.

Table 9: Power Consumption for Reference in System (RM530N-GL + QTM545)

Test Case	Power Consumption	Unit
Peak DL (ENDC: mmWave DL 4CC + sub-6 DL 1CA)	7.6	W
mmWave Max UL	8.8	W

Table 10: System Configuration Under Test

Test Case	Details
Peak DL (ENDC: mmWave DL 4CC + LTE DL 4CA)	● DL 4.0 Gbps, peak DL data rate in mmWave + LTE EN-DC mode ● mmWave DL 4CC, 100 MHz/CC ● Duty cycle: ~97/3, n260, Rx = -88 dBm, 64QAM, 2 × 2 MIMO ● LTE 4CC DL 20 MHz/CC, 256QAM.
mmWave DL 4CC + mmWave UL 22 dBm	● DL 2.4 Gbps/UL 40 Mbps ● mmWave: 100 MHz BW/CC, DL/UL duty cycle: ~60/40, n261

1CC + LTE UL 23 dBm	● mmWave DL: Rx = -88 dBm, 64QAM, 5H + 5V, 2 ×2 MIMO ● mmWave UL: Tx = 22 dBm (TRP), 5H + 5V, SISO, QPSK ● LTE: FDD B3, Tx = 23 dBm, 1 UL, QPSK

4 Radome Design

The radome is a dome-shaped structure which protects QTM545 from harsh environmental conditions, while allowing QTM545 to transmit or receive electromagnetic signals without any distortion or attenuation.

Electrical factors for the radome design are dielectric constant and loss tangent:

- The dielectric constant of the radome material must be a known parameter before design, as it can affect the distortion.
- The smaller the loss tangent of the radome material is, the better performance of attenuation the module will have.

Warranty standard for the radome design also includes water intrusion, surface degradation and overall structure of lifetime. The five radome designs are as follows:

Type One:

- If the dielectric constant is more than 2, it is recommended that the thickness of the radome be 0.5 times the effective wavelength (equivalent resistance effector).
- Place the radome as far away from the antenna as possible, with an interval of about 5–10 free space wavelengths to avoid electromagnetic mutual inductance.
- If the spacing between the radome and the antenna array is < 5 × wavelength, a “radome + array” co-simulation is necessary to avoid unexpected performance degradation.

Type Two:

- If the dielectric constant is less than 2, especially around 1.00053 like air, there is no need to consider the thickness of the radome so long as the structural robust to wind load and water intrusion is ensured.
- No need to consider the spacing between the radome and the antenna.

Type Three:

- If the thickness of radome is < 1/10 electrically wavelength, there is no need to consider the dielectric constant and the placement of radome so long as the structural robust is ensured.

Type Four:

- Radome with a sandwich multilayered wall as three layers, two high dielectric constant skins and a low-density core.
- The thickness of skin is < 1/10 electrically wavelength, and the dielectric constant of core is as small as air.

5 Appendix References

Table 11: Terms and Abbreviations

Abbreviation	Description
3GPP	Third Generation Partnership Project
5G	Fifth Generation
BB	Baseband
BF	Beamforming
BW	Bandwidth
CC	Carrier Component
DUT	Device Under Test
ED (Copper)	Electro-Deposited (Copper)
EIRP	Effective Isotropic Radiated Power
EMI	Electromagnetic Interference
ENDC	New Radio Dual Connectivity
EVB	Evaluated Board
FDD	Frequency Division Duplexing
FPC	Flexible Printed Circuit
IF	Intermediate Frequency
IL	Insertion Loss
IR	Inductive Resistor
LO	Local Oscillator
NR FR2	New Radio Frequency Range 2
MIMO	Multiple Input Multiple Output

mmWave	Millimeter Wave
OD	Outside Diameter
PCB	Printed Circuit Board
PMU	Power Management Unit
PMIC	Power Management Integrated Circuit
QPSK	Quadrature Phase Shift Keying
RA (Copper)	Rolled Annealed (Copper)
RFIC	Radio Frequency Integrated Circuit
SISO	Single Input Single Output
Ta	Ambient Temperature
Tc	Case Temperature
TDD	Time Division Duplex
TIM	Thermal Interface Material
Tj	Junction Temperature
TRP	Total Radiated Power
UE	User Equipment
V_{IO}	Input Offset Voltage