Hardware Integration Guide

August 22, 2022

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1. Introduction

The Dejero Labs Inc EM9191 Embedded Module is a FirstNet-ready (B14 LTE) M.2 module and provides 5G NR Sub-6G, 5G mmWave, 4G LTE advanced Pro, 3G (HSPA+, UMTS), and GNSS connectivity for a wide range of devices and purposes, including business, personal, and portable computing and communication devices, IoT devices, M2M applications and industrial use cases.

EM9191 Embedded Modules are available in a variety of region-specific and function-specific SKUs, including both 5G NR Sub-6G and 5G mmWave-capable variants.

1.1. Accessories

A hardware development kit is available for M.2 modules. The kit contains hardware components for evaluating and developing with the module, including:

- Development board
- Cables
- Antennas
- Other accessories

For over-the-air 5G and LTE testing, ensure that an appropriate antenna is being used.

1.2. Required Connectors

Table 1-1 describes the connectors used to integrate the EM9191 Embedded Module into your host device.

Table 1-1 Required Host-Module Connectors[1]

Connector Type	Description
RF cables — 5G NR Sub-6G/ LTE/GNSS	• Mate with M.2-spec connectors • Four connector jacks (mate with I-PEX 20448-001R-081 or equivalent)
RF cables — mmWave	• Eight connector jacks (mate with I-PEX 20955-001R-13 or equivalent) • Two cables for each mmWave antenna module (up to 8 cables in total)
EDGE (67 pin)	• Slot B compatible — Per the M.2 standard (*PCI Express M.2™ Specification Revision 3.0, Version 1.2*), a generic 75-pin position EDGE connector on the motherboard uses a mechanical key to mate with the 67-pin notched module connector. • Manufacturers include LOTES (part #APCI0018-P001A01), Kyocera, JAE, Tyco, and Longwell.
SIM	• Industry-standard connector.

1. Manufacturers/part numbers are for reference only and are subject to change. Choose connectors that are appropriate for your own design.

2. Power

2.1. Power Supply

The host provides power to the EM9191 through multiple power and ground pins as summarized in Table 2-1.

The host must provide safe and continuous power (via battery or a regulated power supply) at all times; the module does not have an independent power supply, or protection circuits to guard against electrical issues.

Table 2-1 Power and Ground Specifications

Name	Pins	Specification	Min	Typ	Max	Units
VCC (3.3V)	2, 4, 24, 38, 68, 70, 72, 74	Voltage range	3.135	3.3	4.4	V
		Ripple voltage	-	-	100	mV_{pp}
		Peak Current	-	-	4000	mA
		Continuous Current	-	TBD	-	mA
GND	3, 5, 11, 27, 33, 39, 45, 51, 57, 71, 73		-	0	-	V

2.2. Module Power States

The module has five power states, as described in Table 2-2.

Table 2-2 Module Power States

State	Details	Host Is Powered	Host Interface Active	RF Enabled

Normal (Default State)	• Module is active
	• Default state. Occurs when VCC is first applied, Full_Card_Power_Off# is deasserted (pulled high), and W_DISABLE# is deasserted
	• Module is capable of placing/receiving calls, or establishing data connections on the wireless network
	• Current consumption is affected by several factors, including:
	  · Radio band being used
	  · Transmit power
	  · Receive gain settings
	  · Data rate
		✓	✓	✓

State	Details	Host Is Powered	Host Interface Active	RF Enabled

Low Power (Airplane Mode)	• Module is active
	• Module enters this state:
	  · Under host interface control:
	    · Host issues AT+CFUN=0 (3GPP TS 27.007), or
	    · Host asserts W_DISABLE#, after AT!PCOFFEN=0 has been issued.
	  · Automatically, when critical temperature or voltage trigger limits have been reached)
		✓	✓	-

Sleep	• Normal state of module between calls or data connections • Module cycles between wake (polling the network) and sleep, at network provider-determined interval.	✓	-	-
Off	• Host keeps module powered off by asserting Full_Card_Power_Off# (signal pulled low or left floating) • Module draws minimal current	✓	-	-
Disconnected	Host power source is disconnected from the module and all voltages associated with the module are at 0 V.	-	-	-

2.2.1. Power State Transitions

The module uses state machines to monitor supply voltage and operating temperature and notifies the host when critical threshold limits are exceeded. (See Table 2-3 for trigger details and Figure 2-1 for state machine behavior.)

Power state transitions may occur:

- Automatically, when critical supply voltage or module temperature trigger levels are encountered.
- Under host control, using available AT commands in response to user choices (for example, opting to switch to airplane mode) or operating conditions.

Table 2-3 Power State Transition Trigger Levels

Transition	Voltage		Temperature[1]		Notes
	Trigger	V	Trigger	°C	
Normal to Low Power	VOLT_HI_CRIT	4.6	TEMP_LO_CRIT	-45	RF activity suspended
	VOLT_LO_CRIT	2.9	TEMP_HI_CRIT	118	
Low Power to Normal	VOLT_HI_NORM	4.4	TEMP_NORM_LO	-30	RF activity resumed
Low Power to Normal Or Remain in Normal (Remove warnings)	VOLT_LO_NORM	3.135	TEMP_HI_NORM	100	
Normal (Issue warning)	VOLT_LO_WARN	3.135	TEMP_HI_WARN	100	In the TEMP_HI_WARN state, the module may have reduced performance (Class B temperature range).
Power off/on (Host-initiated)	-	-	-	-	Power off recommended when supply voltage or module operating temperature is critically low or high.

1. Module junction temperature at the printed circuit board.

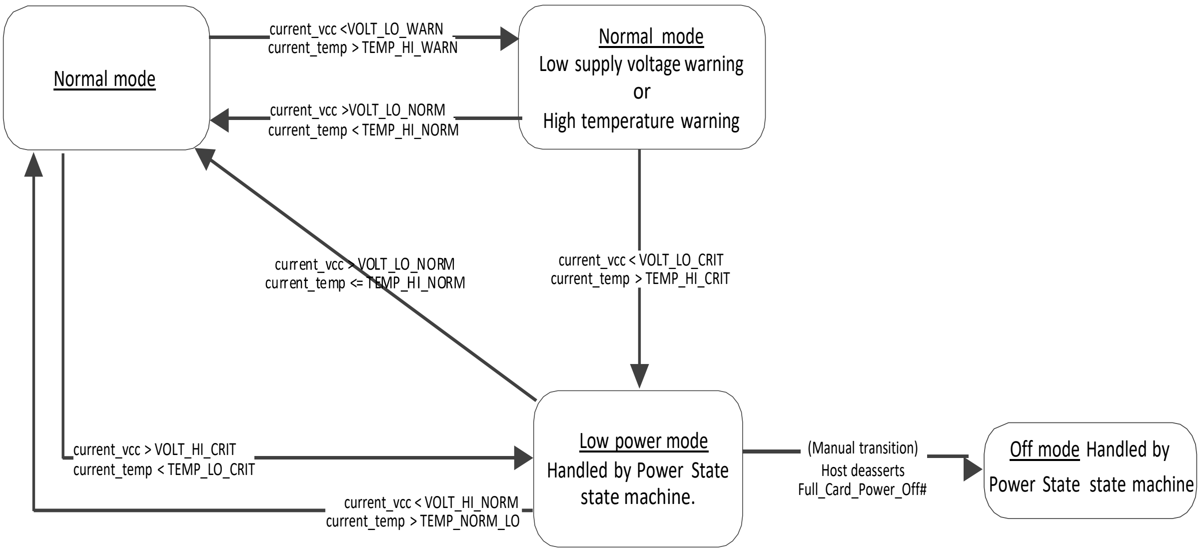

Figure 2-1 Voltage/Temperature Monitoring State Machines

Note: Make sure that your system design provides sufficient cooling for the module.

3. RF Specifications

The EM9191 includes Four MHF4 RF connectors for use with host-supplied antennas, and eight MHF7S connectors for use with up to four mmWave antenna modules (2 connectors per antenna module):

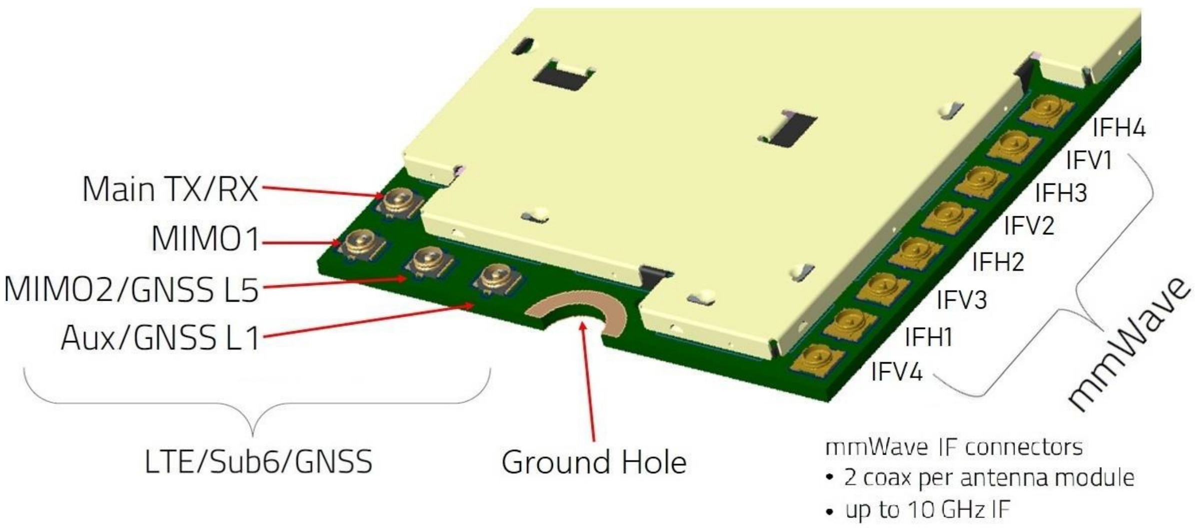

Figure 3-1 Module Connectors Include Image with Spacing Info

- Sub-6G/GNSS connectors:
  - Main: Primary Tx/PRx path for 3G/4G/5G (except for n41)
  - Auxiliary: Diversity Rx (except for n41) and GNSS L1
  - MIMO1: MIMO1 Rx Path and n41 TRx
  - MIMO2: MIMO2 Rx Path and n41 DRx and GNSS L5
- mmWave connectors:
  - Eight connectors — Up to four mmWave antenna modules (QTM525 or QTM527), two connectors as a pair (H/V) for each. The EM9190 module does not have integrated antennas.
  - Refer to Table 3-1 for each pair of coaxial connections. For low-power usage, if not all 4 QTM525 modules are equipped, integration sequence from QTM0 to QTM3 is recommended, leave unused connectors NC (Contact Dejero Labs Inc as the RFC has to be updated to reflect the number of QTMs). Note that for high-power usage, it's not recommended to leave any QTM527 NC as it will violate 3GPP EIRP compliance for PC1.

Table 3-1 mmWave Port Assignment

QTM	P_ON	QTM525 IF port <-> mmWave IF Connector		QTM527 IF port <-> mmWave IF Connector	
		IF1	IF2	IF1	IF2
QTM0	QTM0_PON	QTM0_H <-> IFH1	QTM0_V <-> IFV4	QTM0_H <-> IFH1	QTM0_V <-> IFV4
QTM1	QTM1_PON	QTM1_H <-> IFH4	QTM1_V <-> IFV1	QTM1_H <-> IFH2	QTM1_V <-> IFV3
QTM2	QTM2_PON	QTM2_H <-> IFH2	QTM2_V <-> IFV3	QTM2_H <-> IFH3	QTM2_V <-> IFV2
QTM3	QTM3_PON	QTM3_H <-> IFH3	QTM3_V <-> IFV2	QTM3_H <-> IFH4	QTM3_V <-> IFV1

3.1. RF Connections

When attaching antennas to the module:

- Sub-6G /GNSS connectors:
  - Use RF plug connectors that are compatible with the following RF receptacle connectors: I-PEX (20449-001E (MHF4)).
  - Match coaxial connections between the module and the antenna to 50Ω.
  - Minimize RF cable losses to the antenna; the recommended maximum cable loss for antenna cabling is 0.5 dB.
- mmWave connectors:
  - Use RF plug connectors that are compatible with the following RF receptacle connectors: I-PEX (20956-001E-01 (MHF7S)).
- To ensure best thermal performance, use the ground hole (if possible) to attach (ground) the device to a metal chassis.

Note: *If antenna connection is shorted or open, the modem will not sustain permanent damage.*

3.1.1. Shielding

The module is fully shielded to protect against EMI and must not be removed.

3.2. Sub-6G Antennas and Cabling

When selecting the Sub-6G antennas and cables, it is critical to RF performance to match antenna gain and cable loss.

Note: *There is no explicit list of antennas required in the application. The PWB-6-60-RSMAP Wide Band 4G/5G Terminal Paddle Antenna has been verified as a reference. For detailed electrical performance criteria, see* *Antenna Specification*.

Choosing the Correct Sub-6G Antenna and Cabling

When matching antennas and cabling:

- The antenna (and associated circuitry) should have a nominal impedance of 50Ω with a return loss of better than 10 dB across each frequency band of operation.
- The system gain value affects both radiated power and regulatory (FCC, IC, CE, etc.) test results.

Designing Custom Sub-6G Antennas

Consider the following points when designing custom antennas:

- A skilled RF engineer should do the development to ensure that the RF performance is maintained.
- If multiple modules will be installed on the same platform, you may want to develop separate antennas for maximum performance.

Determining the Sub-6G Antenna's Location

When deciding where to put the antennas:

- Antenna location may affect RF performance. Although the module is shielded to prevent interference in most applications, the placement of the antenna is still very important — if the host device is insufficiently shielded, high levels of broadband or spurious noise can degrade the module's performance.
- Connecting cables between the module and the antenna must have 50Ω impedance. If the impedance of the module is mismatched, RF performance is reduced significantly.

- Antenna cables should be routed, if possible, away from noise sources (switching power supplies, LCD assemblies, etc.). If the cables are near the noise sources, the noise may be coupled into the RF cable and into the antenna. See Interference from Other Wireless Devices.

Disabling the Auxiliary (Diversity) Antenna

Certification testing of a device with an integrated EM9191 may require the module's main and diversity antennas to be tested separately.

To facilitate this testing, receive diversity can be enabled/disabled using AT commands:

- **!RXDEN** — used to enable/disable diversity for single-cell call (no carrier aggregation).
- **!LTERXCONTROL** — used to enable/disable paths (in carrier aggregation scenarios) after a call is set up.

Note: *LTE networks expect modules to have more than one antenna enabled for proper operation. Therefore, customers must not commercially deploy their systems with the diversity antenna disabled.*

A diversity antenna is used to improve connection quality and reliability through redundancy. Because two antennas may experience different interference effects (signal distortion, delay, etc.), when one antenna receives a degraded signal, the other may not be similarly affected.

3.3. Ground Connection

When connecting the module to system ground:

- Prevent noise leakage by establishing a very good ground connection to the module through the host connector.
- Connect to system ground using the ground hole shown in Figure 3-1.
- Minimize ground noise leakage into the RF. Depending on the host board design, noise could potentially be coupled to the module from the host board. This is mainly an issue for host designs that have signals traveling along the length of the module, or circuitry operating at both ends of the module interconnects.

3.4. Interference and Sensitivity

Several interference sources can affect the module's RF performance (RF desense). Common sources include power supply noise and device-generated RF.

RF desense can be addressed through a combination of mitigation techniques (Methods to Mitigate Decreased Rx Performance) and radiated sensitivity measurement (Radiated Sensitivity Measurement).

Note: *The EM9191 is based on ZIF (Zero Intermediate Frequency) technologies. When performing EMC (Electromagnetic Compatibility) tests, there are no IF (Intermediate Frequency) components from the module to consider.*

3.4.1. Interference from Other Wireless Devices

Wireless devices operating inside the host device can cause interference that affects the module.

To determine the most suitable locations for antennas on your host device, evaluate each wireless device's radio system, considering the following:

- Any harmonics, sub-harmonics, or cross-products of signals generated by wireless devices that fall in the module's Rx range may cause spurious response, resulting in decreased Rx performance.

- The Tx power and corresponding broadband noise of other wireless devices may overload or increase the noise floor of the module's receiver, resulting in Rx desense.

The severity of this interference depends on the closeness of the other antennas to the module's antenna. To determine suitable locations for each wireless device's antenna, thoroughly evaluate your host device's design.

3.4.2. Host-generated RF Interference

All electronic computing devices generate RF interference that can negatively affect the receive sensitivity of the module.

Proximity of host electronics to the antenna in wireless devices can contribute to decreased Rx performance. Components that are most likely to cause this include:

- Microprocessor and memory
- Display panel and display drivers
- Switching-mode power supplies

3.4.3. Device-generated RF Interference

The module can cause interference with other devices. Wireless devices such as embedded modules transmit in bursts (pulse transients) for set durations (RF burst frequencies). Hearing aids and speakers convert these burst frequencies into audible frequencies, resulting in audible noise.

3.4.4. Methods to Mitigate Decreased Rx Performance

It is important to investigate sources of localized interference early in the design cycle. To reduce the effect of device-generated RF on Rx performance:

- Put the antenna as far as possible from sources of interference. The drawback is that the module may be less convenient to use.
- Shield the host device. The module itself is well shielded to avoid external interference. However, the antenna cannot be shielded for obvious reasons. In most instances, it is necessary to employ shielding on the components of the host device (such as the main processor and parallel bus) that have the highest RF emissions.
- Filter out unwanted high-order harmonic energy by using discrete filtering on low frequency lines.
- Form shielding layers around high-speed clock traces by using multi-layer PCBs.
- Route antenna cables away from noise sources.

3.4.5. Radiated Spurious Emissions (RSE)

When designing an antenna for use with embedded modules, the host device with an embedded module must satisfy any applicable standards/local regulatory bodies for radiated spurious emission (RSE) for receive-only mode and for transmit mode (transmitter is operating).

Note that antenna impedance affects radiated emissions, which must be compared against the conducted 50Ω emissions baseline. (Dejero Labs Inc embedded modules meet the 50Ω conducted emissions requirement.)

3.5. Radiated Sensitivity Measurement

A wireless host device contains many noise sources that contribute to a reduction in Rx performance.

To determine the extent of any receiver performance desensitization due to self-generated noise in the host device, over-the-air (OTA) or radiated testing is required. This testing can be performed using your own OTA test chamber for in-house testing.

3.5.1. Dejero Labs Inc’s Sensitivity Testing and Desensitization Investigation

Although embedded modules are designed to meet network operator requirements for receiver performance, they are still susceptible to various performance inhibitors.

3.5.2. Sensitivity vs. Frequency

Sensitivity definitions for supported RATs:

- UMTS bands — sensitivity is defined as the input power level in dBm that produces a BER (Bit Error Rate) of 0.1%. Sensitivity should be measured at all UMTS frequencies across each band.
- LTE bands — sensitivity is defined as the RF level at which throughput is 95% of maximum.
- 5G NR Sub-6G bands — sensitivity is defined as RF level at which throughput is 95% of maximum.

3.6. Supported Frequencies

The EM9191 supports data operation on 5G NR, 4G LTE and 3G networks over the bands described in Table 3-2.

Table 3-2 RF Band Support

Technology	Bands	
5G	mmWave[1]	n257, n258, n260, n261
	Sub-6G	n1, n2, n3, n5, n28, n41, n66, n71, n77, n78, n79
LTE	LTE	B1, B2, B3, B4, B5, B7, B8, B12, B13, B14, B17, B18, B19, B20, B25, B26, B28, B29, B30[2], B32, B34, B38, B39, B40, B41, B42, B46[3], B48, B66, B71
3G	HSPA+/WCDMA	Bands 1, 2, 3, 4, 5, 6, 8, 9, 19
GNSS[1]	L1	GPS/QZSS L1, GLONASS G1, Galileo E1, BeiDou B1i
	L5	GPS L5, GAL E5a, QZSS L5, BDS B2a

1. EM9191 hardware include IF and BB part for mmWave support, it has to work with Qualcomm QTM525 or QTM527 chipset to implement mmWave. QTM527 and QTM527 array with dedicate power management, RF power amplifiers and frequency converters integrated.
2. Devices can choose to operate B30 as Tx/Rx or Rx only.
3. LTE-LAA

See following tables for supported bands frequency and bandwidth:

Table 3-3 Supported Frequency Bands, by RAT (5G/LTE/3G)

Band#	5G (n<band#>)	LTE (B<band#>)	3G (Band<band#>)	Frequency (Tx)	Frequency (Rx)
1	Yes	Yes	Yes	1920–1980 MHz	2110–2170 MHz
2	Yes	Yes	Yes	1850–1910 MHz	1930–1990 MHz
3	Yes	Yes	Yes	1710–1785 MHz	1805–1880 MHz
4		Yes	Yes	1710–1755 MHz	2110–2155 MHz
5	Yes	Yes	Yes	824–849 MHz	869–894 MHz
6			Yes	830–840 MHz	875–885 MHz
7		Yes		2500–2570 MHz	2620–2690 MHz
8		Yes	Yes	880–915 MHz	925–960 MHz
9			Yes	1749.9–1784.9 MHz	1844.9–1879.9 MHz
12		Yes		699–716 MHz	729–746 MHz
13		Yes		777–787 MHz	746–756 MHz
14		Yes		788–798 MHz	758–768 MHz
17		Yes		704–716 MHz	734–746 MHz
18		Yes		815–830 MHz	860–875 MHz
19		Yes	Yes	830–845 MHz	875–890 MHz
20		Yes		832–862 MHz	791–821 MHz
25		Yes		1850–1915 MHz	1930–1995 MHz
26		Yes		814–849 MHz	859–894 MHz
28	Yes	Yes		703–748 MHz	758–803 MHz
29		Yes		N/A	717–728 MHz
30		Yes		2305–2315 MHz *Note: B30 Tx is disabled.*	2350–2360 MHz
32		Yes		N/A	1452–1496 MHz
34		Yes		2010–2025 MHz (TDD)	
38		Yes		2570–2620 MHz (TDD)	
39		Yes		1880–1920 MHz (TDD)	
40		Yes		2300–2400 MHz (TDD)	
41	Yes	Yes		2496–2690 MHz (TDD)	
42		Yes		3400–3600 MHz (TDD)	
46		Yes		N/A	5150–5925 MHz (TDD)
48		Yes		3550–3700 MHz (TDD)	
66	Yes	Yes		1710–1780 MHz	2110–2200 MHz
71	Yes	Yes		663–698 MHz	617–652 MHz
77	Yes			3300–4200 MHz (TDD)	
78	Yes			3300–3800 MHz (TDD)	
79	Yes			4400–5000 MHz (TDD)	
257	Yes			26500–29500 MHz (TDD)	
258	Yes			24250–27500 MHz (TDD)	
260	Yes			37000–40000 MHz (TDD)	
261	Yes			27500–28350 MHz (TDD)	

Table 3-4 LTE Bandwidth Support[1]

Band	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
B1			Yes	Yes	Yes	Yes
B2	Yes	Yes	Yes	Yes	Yes[2]	Yes[2]
B3	Yes	Yes	Yes	Yes	Yes[2]	Yes[2]
B4	Yes	Yes	Yes	Yes	Yes	Yes
B5	Yes	Yes	Yes	Yes[2]		
B7			Yes	Yes	Yes[3]	Yes[2,3]
B8	Yes	Yes	Yes	Yes[2]		
B12	Yes	Yes	Yes[2]	Yes[2]		
B13			Yes[2]	Yes[2]		
B14			Yes[2]	Yes[2]		
B17			Yes[2]	Yes[2]		
B18			Yes	Yes[2]	Yes[2]	
B19			Yes	Yes[2]	Yes[2]	
B20			Yes	Yes[2]	Yes[2]	Yes[2]
B25	Yes	Yes	Yes	Yes	Yes[2]	Yes[2]
B26	Yes	Yes	Yes	Yes[2]	Yes[2]	
B28		Yes	Yes	Yes[2]	Yes[2]	Yes[2,3]
B29		Yes	Yes	Yes		
B30			Yes	Yes[2]		
B32			Yes	Yes	Yes	Yes
B34			Yes	Yes	Yes	
B38			Yes	Yes	Yes[3]	Yes[3]
B39			Yes	Yes	Yes[3]	Yes[3]
B40			Yes	Yes	Yes	Yes
B41			Yes	Yes	Yes	Yes
B42			Yes	Yes	Yes	Yes
B46				Yes		Yes
B48			Yes	Yes	Yes	Yes
B66	Yes	Yes	Yes	Yes	Yes	Yes
B71	Yes	Yes	Yes	Yes[2]	Yes[2]	Yes[2]

1. Table contents are derived from 3GPP TS 36.521-1 v15.5.0, table 5.4.2.1-1.

2. Bandwidth for which a relaxation of the specified UE receiver sensitivity requirement (Clause 7.3 of 3GPP TS 36.521-1 v15.5.0) is allowed.

3. Bandwidth for which uplink transmission bandwidth can be restricted by the network for some channel assignments in FDD/TDD co-existence scenarios in order to meet unwanted emissions requirements (Clause 6.6.3.2 of 3GPP TS 36.521-1 v15.5.0).

Table 3-5 NR Bandwidth Support[1,2,3]

Band	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz
n1	Yes	Yes	Yes	Yes								
n2	Yes	Yes	Yes	Yes								
n3	Yes	Yes	Yes	Yes								

Band	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz
n5	Yes	Yes	Yes	Yes								
n28	Yes	Yes	Yes	Yes								
n41				Yes			Yes	Yes	Yes	Yes	Yes[4]	Yes
n66	Yes	Yes	Yes	Yes								
n71	Yes	Yes	Yes	Yes								
n77							Yes	Yes	Yes	Yes	Yes[4]	Yes
n78				Yes			Yes	Yes	Yes	Yes	Yes[4]	Yes
n79							Yes	Yes	Yes	Yes		Yes

1. Table contents are derived from 3GPP TS 38.521-1 v15.3.0, table 5.3.5-1.
2. For FR1 Sub-6G bands, NR TDD Bands (n41/77/78/79), only SCS 30KHz is supported, and for other FDD bands, only SCS 15KHz is supported.
3. For FR2 mmWave bands, only 50MHz and 100MHz bandwidth is supported.
4. This UE channel bandwidth is optional in Release 15.

3.7. Antenna Specification

This appendix describes recommended electrical performance criteria for Sub-6G, GNSS, and mmWave antennas used with embedded modules.

The performance specifications described in this section are valid while antennas are mounted in the host device with antenna feed cables routed in their final application configuration.

Note: *Antennas should be designed* ***before*** *the industrial design is finished to make sure that the best antennas can be developed.*

3.7.1. Recommended WWAN Antenna Specifications

Table 3-6 Antenna Requirements[1]

Parameter	Requirements	Comments
Antenna System	(NR/LTE) External multi-band 4x4 MIMO antenna system (Ant1/ Ant2/Ant3/Ant4)[2] (3G) External multi-band antenna system with diversity (Ant1/Ant2)	If Ant2 or Ant3 includes GNSS, then it must also satisfy requirements in Table 3-7.
Operating Bands — Ant1	All supporting Tx and Rx frequency bands.	
Operating Bands — Ant2/3/4	All supporting Rx frequency bands, plus GNSS frequency bands if Ant2 is used in shared Diversity/MIMO/GNSS mode.	
VSWR of Ant1 and Ant2	• < 2:1 (recommended) • < 3:1 (worst case)	On all bands including band edges

Parameter	Requirements	Comments
Total Radiated Efficiency	> 50% on all bands	• Measured at the RF connector. • Includes mismatch losses, losses in the matching circuit, and antenna losses, excluding cable loss. • Dejero Labs Inc recommends using antenna efficiency as the primary parameter for evaluating the antenna system. • Peak gain is not a good indication of antenna performance when integrated with a host device (the antenna does not provide omni-directional gain patterns). Peak gain can be affected by antenna size, location, design type, etc. — the antenna gain patterns remain fixed unless one or more of these parameters change.
Radiation Patterns	Nominally Omni-directional radiation pattern in azimuth plane.	
Envelope Correlation Coefficient between Ant	• < 0.5 on Rx bands below 960 MHz • < 0.2 on Rx bands above 1.4 GHz	
Mean Effective Gain of Ant1 and Ant2 (MEG1, MEG2)	≥ -3 dBi	
Ant1 and Ant2 Mean Effective Gain Imbalance | MEG1 / MEG2 |	• < 2 dB for MIMO operation • < 6 dB for diversity operation	
Maximum Antenna Gain	Must not exceed antenna gains due to RF exposure and ERP/ EIRP limits, as listed in the module's FCC grant.	See Important Compliance Information for the United States and Canada.
Isolation	• >10dB for all antennas at all bands frequency range. • >20dB for Ant1 and Ant4 at B41 frequency range.	• If antennas can be moved, test all positions for both antennas. • Make sure all other wireless devices (Bluetooth or WLAN antennas, etc.) are turned OFF to avoid interference.
Power Handling	>1W	• Measure power endurance over 4 hours (estimated talk time) using a 1 W CW signal — set the CW test signal frequency to the middle of each supporting Tx band. • Visually inspect device to ensure there is no damage to the antenna structure and matching components. • VSWR/TIS/TRP measurements taken before and after this test must show similar results.

1. These worst-case VSWR figures for the transmitter bands may not guarantee RSE levels to be within regulatory limits. The device alone meets all regulatory emissions limits when tested into a cabled (conducted) 50Ω system. With antenna designs with up to 2.5:1 VSWR or worse, the radiated emissions could exceed limits. The antenna system may need to be tuned in order to meet the RSE limits as the complex match between the module and antenna can cause unwanted levels of emissions. Tuning may include antenna pattern changes, phase/delay adjustment, passive component matching. Examples of the application test limits would be included in FCC Part 22, Part 24 and Part 27, test case 4.2.2 for WCDMA (ETSI EN 301 908-1), where applicable.

2. Ant1 - Primary, Ant2 - Secondary (Diversity/GNSS L1), Ant3 - MIMO1 Rx path and n41 TRx, Ant4 - MIMO2 Rx path, n41 DRx path and GNSS L5.

3.7.2. Recommended GNSS Antenna Specifications

Table 3-7 GNSS Antenna Requirements

Parameter	Requirements	Comments
Frequency Range	• Wide-band GNSS: 1559–1606 MHz recommended • Narrow-band GPS: 1575.42 MHz ±2 MHz minimum • Narrow-band Galileo: 1575.42 MHz ±2 MHz minimum • Narrow-band BeiDou: 1561.098 MHz ±2 MHz minimum • Narrow-band GLONASS: 1601.72 MHz ±4.2 MHz minimum • Narrow-band QZSS: 1575.42 MHz ±2 MHz minimum	
Field of View (FOV)	• Omni-directional in azimuth • -45° to +90° in elevation	
Polarization (Average Gv/Gh)	>0 dB	Vertical linear polarization is sufficient.
Free Space Average gain (Gv+Gh) over FOV	> -6 dBi (preferably > -3 dBi)	Gv and Gh are measured and averaged over -45° to +90° in elevation, and ±180° in azimuth.
Gain	• Maximum gain and uniform coverage in the high elevation angle and zenith. • Gain in azimuth plane is not desired.	
Average 3D Gain	> -5 dBi	
Isolation between GNSS and ANTx for WWAN Tx	> 15 dB in all uplink bands and GNSS Rx Bands	
Typical VSWR	< 2.5:1	
Polarization	Any other than LHCP (left-hand circular polarized) is acceptable.	

Note: GNSS active antenna is forbidden to use.

4. Regulatory Compliance and Industry Certification

This module is designed to meet, and upon commercial release, will meet the requirements of the following regulatory bodies and regulations, where applicable:

- Federal Communications Commission (FCC) of the United States
- The National Communications Commission (NCC) of Taiwan, Republic of China
- The Certification and Engineering Bureau of Industry Canada (IC)
- The European Union Radio Equipment Directive 2014/53/EU and RoHS Directive 2011/65/EU
- Russia Federal Agency of Communication (FAC)
- China CCC, NAL and SRRC
- South Korea KCC

Additional testing and certification may be required for the end product with an embedded EM9191 module and are the responsibility of the OEM.

4.1. Important Notice

Because of the nature of wireless communications, transmission and reception of data can never be guaranteed. Data may be delayed, corrupted (i.e., have errors) or be totally lost. Although significant delays or losses of data are rare when wireless devices such as the Dejero Labs Inc module are used in a normal manner with a well-constructed network, the Dejero Labs Inc module should not be used in situations where failure to transmit or receive data could result in damage of any kind to the user or any other party, including but not limited to personal injury, death, or loss of property. Dejero Labs Inc and its affiliates accept no responsibility for damages of any kind resulting from delays or errors in data transmitted or received using the Dejero Labs Inc module, or for failure of the Dejero Labs Inc module to transmit or receive such data.

4.2. Safety and Hazards

Do not operate your EM9191 module:

- In areas where blasting is in progress
- Where explosive atmospheres may be present including refueling points, fuel depots, and chemical plants
- Near medical equipment, life support equipment, or any equipment which may be susceptible to any form of radio interference. In such areas, the EM9191 module **MUST BE POWERED OFF**. Otherwise, the EM9191module can transmit signals that could interfere with this equipment.

In an aircraft, the EM9191 module **MUST BE POWERED OFF**. Otherwise, the EM9191 module can transmit signals that could interfere with various onboard systems and may be dangerous to the operation of the aircraft or disrupt the cellular network. Use of a cellular phone in an aircraft is illegal in some jurisdictions. Failure to observe this instruction may lead to suspension or denial of cellular telephone services to the offender or legal action, or both.

Some airlines may permit the use of cellular phones while the aircraft is on the ground and the door is open. The EM9191 module may be used normally at this time.

4.3. Important Compliance Information for the United States and Canada

The EM9191 module, upon commercial release, will have been granted modular approval for mobile applications. Integrators may use the EM9191 module in their final products without additional FCC/IC (Industry Canada) certification if they meet the following conditions. Otherwise, additional FCC/IC approvals must be obtained.

1. At least 20 cm separation distance between the antenna and the user's body must be maintained at all times.
2. To comply with FCC/IC regulations limiting both maximum RF output power and human exposure to RF radiation, the maximum antenna gain including cable loss in a mobile-only exposure condition must not exceed the limits stipulated in Table 4-1.
3. The EM9191 module may transmit simultaneously with other collocated radio transmitters within a host device, provided the following conditions are met:
   - Each collocated radio transmitter has been certified by FCC/IC for mobile application.
   - At least 20 cm separation distance between the antennas of the collocated transmitters and the user's body must be maintained at all times.
   - The radiated power of a collocated transmitter must not exceed the EIRP limit stipulated in Table 4-1.

Table 4-1 Antenna Gain and Collocated Radio Transmitter Specifications

Device	Operating Mode	Tx Freq Range (MHz)		Max Time-Avg Cond. Power (dBm)	Antenna Gain Limit (dBi)	
					Standalone	Collocated
EM9191	WCDMA Band 2	1850	1910	24.5	8.5	8
	WCDMA Band 4	1710	1755	24.5	5.5	5.5
	WCDMA Band 5	824	849	24.5	6	5.5
	LTE B2	1850	1910	24	8.5	8
	LTE B4	1710	1755	24	5.5	5.5
	LTE B5	824	849	24	6	5.5
	LTE B7	2500	2570	24.8	5.5	5.5
	LTE B12	699	716	24	5.5	5
	LTE B13	777	787	24	5.5	5
	LTE B14	788	798	24	5.5	5
	LTE B17	704	716	24	5.5	5
	LTE B25	1850	1915	24	8.5	8
	LTE B26	814	849	24	6	5.5
	LTE B30	2305	2315	24	0	0
	LTE B38	2570	2620	24.8	7	7

Device	Operating Mode	Tx Freq Range (MHz)		Max Time-Avg Cond. Power (dBm)	Antenna Gain Limit (dBi)	
					Standalone	Collocated
	LTE B41	2496	2690	24.8	7	7
	LTE B41-HPUE	2496	2690	26	7	7
	LTE B48	3550	3700	24.8	-1.8	-1.8
	LTE B66	1710	1780	24	5.5	5.5
	LTE B71	663	698	24	5.5	5
	5G NR n2	1850	1910	24.5	8.5	8
	5G NR n5	824	849	24.5	6	5.5
	5G NR n41	2496	2690	24.5	7	7
	5G NR n66	1710	1780	24.5	5.5	5.5
	5G NR n71	663	698	24.5	5.5	5
Collocated Transmitters	WLAN 2.4 GHz	2400	2500	20	-	5
	WLAN 5 GHz	5150	5850	20	-	8
	Bluetooth	2400	2500	17	-	5

Note: *The FCC and IC have a strict EIRP limit in Band 30 for mobile and portable stations in order to protect adjacent satellite radio, aeronautical mobile telemetry, and deep space network operations. Mobile and portable stations must not have antenna gain exceeding 0 dBi in Band 30. Additionally, both the FCC and IC prohibit the use of external vehicle-mounted antennas for mobile and portable stations in this band.*

Fixed stations may use antennas with higher gain in Band 30 due to relaxed EIRP limits. EM9191 modules used as fixed subscriber stations in Canada or fixed customer premises equipment (CPE) stations in the United States may have an antenna gain up to 9 dBi in Band 30, however, the use of outdoor antennas or outdoor station installations are prohibited except if professionally installed in locations that are at least 20 meters from roadways or in locations where it can be shown that the ground power level of -44 dBm per 5 MHz in the bands 2305–2315 MHz and 2350–2360 MHz or -55 dBm per 5 MHz in the bands 2315–2320 MHz and 2345–2350 MHz will not be exceeded at the nearest roadway. For the purposes of this notice, a roadway includes a highway, street, avenue, parkway, driveway, square, place, bridge, viaduct or trestle, any part of which is intended for use by the general public for the passage of vehicles.

Mobile carriers often have limits on total radiated power (TRP), which requires an efficient antenna.

The end product with an embedded module must output sufficient power to meet the TRP requirement but not too much to exceed FCC/IC's EIRP limit. If you need assistance in meeting this requirement, please contact Dejero Labs Inc.

Airborne operations in LTE Band 48 are prohibited.

4. A label must be affixed to the outside of the end product into which the EM9191 module is incorporated, with a statement similar to the following:

   This device contains FCC ID: Y99DEJEM91, IC: 12762A-DEJEM91.

5. A user manual with the end product must clearly indicate the operating requirements and conditions that must be observed to ensure compliance with current FCC/IC RF exposure guidelines.

The end product with an embedded EM9191 module may also need to pass the FCC Part 15 unintentional emission testing requirements and be properly authorized per FCC Part 15.

Note: If this module is intended for use in a portable device, you are responsible for separate approval to satisfy the SAR requirements of FCC Part 2.1093 and IC RSS-102.

5. Abbreviations

Table 5-1 Abbreviations and Definitions

Abbreviation or Term	Definition
3GPP	3rd Generation Partnership Project
BeiDou	BeiDou Navigation Satellite System A Chinese system that uses a series of satellites in geostationary and middle earth orbits to provide navigational data.
BER	Bit Error Rate — A measure of receive sensitivity
dB	Decibel = 10 x log10 (P1/P2) *P1 is calculated power; P2 is reference power* Decibel = 20 x log10 (V1/V2) *V1 is calculated voltage, V2 is reference voltage*
dBm	A logarithmic (base 10) measure of relative power (dB for decibels); relative to milliwatts (m). A dBm value will be 30 units (1000 times) larger (less negative) than a dBW value, because of the difference in scale (milliwatts vs. watts).
DRX	Discontinuous Reception
EIRP	Effective (or Equivalent) Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FCC	Federal Communications Commission The U.S. federal agency that is responsible for interstate and foreign communications. The FCC regulates commercial and private radio spectrum management, sets rates for communications services, determines standards for equipment, and controls broadcast licensing. Consult http://www.fcc.gov.
FDD	Frequency Division Duplexing
Galileo	A European system that uses a series of satellites in middle earth orbit to provide navigational data.
GCF	Global Certification Forum
GLONASS	Global Navigation Satellite System — A Russian system that uses a series of 24 satellites in middle circular orbit to provide navigational data.
GNSS	Global Navigation Satellite Systems (GPS, GLONASS, BeiDou, and Galileo)
GPS	Global Positioning System An American system that uses a series of 24 satellites in middle circular orbit to provide navigational data.
Host	The device into which an embedded module is integrated
HSPA+	Enhanced HSPA, as defined in 3GPP Release 7 and beyond
Hz	Hertz = 1 cycle/second
IC	Industry Canada
IF	Intermediate Frequency
LTE	Long Term Evolution — a high-performance air interface for cellular mobile communication systems.
MHz	Megahertz = 10e6 Hz
MIMO	Multiple Input Multiple Output — wireless antenna technology that uses multiple antennas at both transmitter and receiver side. This improves performance.
OEM	Original Equipment Manufacturer — a company that manufactures a product and sells it to a reseller.

Abbreviation or Term	Definition
OTA	Over the air (or radiated through the antenna)
PCB	Printed Circuit Board
PST	Product Support Tools
PTCRB	PCS Type Certification Review Board
QZSS	Quasi-Zenith Satellite System — Japanese system for satellite-based augmentation of GPS.
RAT	Radio Access Technology
RF	Radio Frequency
RSE	Radiated Spurious Emissions
SAR	Specific Absorption Rate
Sensitivity (Audio)	Measure of lowest power signal that the receiver can measure.
Sensitivity (RF)	Measure of lowest power signal at the receiver input that can provide a prescribed BER/BLER/ SNR value at the receiver output.
SIM	Subscriber Identity Module. Also referred to as USIM or UICC.
SKU	Stock Keeping Unit — identifies an inventory item: a unique code, consisting of numbers or letters and numbers, assigned to a product by a retailer for purposes of identification and inventory control.
SNR	Signal-to-Noise Ratio
TDD	Time Division Duplexing
TIS	Total Isotropic Sensitivity
TRP	Total Radiated Power
UMTS	Universal Mobile Telecommunications System
VCC	Supply voltage
WCDMA	Wideband Code Division Multiple Access (also referred to as UMTS)
WLAN	Wireless Local Area Network
ZIF	Zero Intermediate Frequency