7 Key Measurement Challenges

Signal Quality
mmWave, Waveform, Fidelity

Lots of Channels
MIMO & Beamforming

Channel
Characterizing & Emulating

Life Beyond Connectors
Over-the-Air

Performance on the Network
Network Emulation

Connect Design & Test
Components & Systems

Field & Drive Test

Protocol R&D
RF/RRM DVT
Functional KPI

Design
Simulate
Validate
Connect
Test
# 3GPP UE & gNB Tx Conformance Test requirement docs

## 3GPP NR UE Tx test requirement

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1: Range 1 Standalone</td>
<td>TS38.101-1 v.15.2.0</td>
<td>TS38.521-1 v.1.0.1</td>
<td>FR1, Conducted</td>
</tr>
<tr>
<td>Part 2: Range 2 Standalone</td>
<td>TS38.101-2 v.15.2.0</td>
<td>TS38.521-2 v.1.0.0</td>
<td>FR2, Radiated</td>
</tr>
<tr>
<td>Part 3: Range 1 and 2 Interworking operation with other radios</td>
<td>TS38.101-3 v.15.2.0</td>
<td>TS38.521-3 v.1.0.0</td>
<td>FR1 and FR2 CA, EN-DC**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FR1 Conducted, FR2 Radiated</td>
</tr>
</tbody>
</table>

(*) v.1.0.x is still draft or pre-release status. (Official version should be v.15.x.x)

(**) EN-DC: E-UTRA and NR Dual Connectivity

## 3GPP NR BTS Tx test requirement

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Minimum Requirement (2018-06)</th>
<th>Conformance Requirement (2018-09 draft)*</th>
<th>gNB</th>
</tr>
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<td>TS38.104 v.15.2.0</td>
<td>TS38.141-1 v.1.0.0</td>
<td>FR1, Conducted</td>
</tr>
<tr>
<td>Part 2: Radiated testing</td>
<td>TS38.104 v.15.2.0</td>
<td>TS38.141-2 v.1.0.0</td>
<td>FR1 and FR2, Radiated</td>
</tr>
</tbody>
</table>

(*) v.1.0.x is still draft or pre-release status. (Official version should be v.15.3.0)
**3GPP gNB Conformance Tests**

**TS38.141 OVERVIEW**

- **R&D**
- **DVT ("I&V")**
- **Conformance Test**
- **Manufacturing**
- **Installation & Maintenance**

Network Equipment Manufacturers must comply with 3GPP Specifications.

**3GPP TS 38.141 Overview**

**5G NR Base Station Conformance Tests**

**Part 1: Conducted**

FR1: 410 MHz – 7.125 GHz

- **Chapter 6 – Transmitter**
  (Power, Signal Quality, Unwanted Emissions, etc.)

- **Chapter 7 – Receiver Characteristics**
  (Dynamic Range, Sensitivity, Selectivity, Blocking, etc.)

- **Chapter 8 – Receiver Performance Requirements**
  (Throughput with fading & HARQ ACK/NACK)

**Part 2: Radiated**

FR1: 410 MHz – 7.125 GHz
FR2: 24.25 GHz – 52.6 GHz

- **Chapter 6 – Transmitter**
  (Power, Signal Quality, Unwanted Emissions, etc.)

- **Chapter 7 – Receiver Characteristics**
  (Dynamic Range, Sensitivity, Selectivity, Blocking, etc.)

- **Chapter 8 – Receiver Performance Requirements**
  (Throughput with fading & HARQ ACK/NACK)
The Good News:

- Higher frequency antenna elements are smaller
- Easier to assemble into electronically steered arrays
- Reduced interference. Energy goes where it’s needed
- Improve performance in dense crowds (5G goal)
- Higher frequencies → wider bandwidths: faster (5G goal)

Challenges:

- Antenna are directional
- Increased complexity with more elements, very small for probing or conducted test
- Multiple antenna arrays required for spherical coverage
- Traditional cabled test methods obsolete – OTA needed

\[ \text{Power}_{RX} = \text{Power}_{TX} + \text{AntGain}_{RX} + \text{AntGain}_{TX} - 20\log_{10}(4\pi R) - 20\log_{10}\left(\frac{f}{c}\right) \]
Static Antenna Performance
- Power vs. angle (EIRP)
- Total Radiated Power (TRP)
- Directivity
- Efficiency/Gain

RF Parametrics
- Packet error-rates
- EIS
- Error-vector-magnitude (EVM)
- ACLR
- Spurious / harmonics

Performance / Signaling
- Beam discovery
- Throughput
- Blocking/interferers
- Handovers (RRM)
Far-Field Test Challenges with mmWave

LONGER FAR-FIELD AND HIGHER PATH LOSS

What is D?

- Fastback Networks V1000
- Facebook Terragraph

What is black box testing?

- 3GPP mandated concept for device conformance testing
- Engineers must treat the position and number of antennas as being unknown
- DUT tested as a “black box” and antenna aperture (D) must be assumed to be the same size as the entire DUT
Far-Field Test Challenges with mmWave

LONGER FAR-FIELD AND HIGHER PATH LOSS

Ideal Plane wave is at \( \infty \)

Figure 5. Beam evolution as a function of distance from an antenna.

Fraunhofer distance \([R]\)
Far-Field Test Challenges with mmWave

LONGER FAR-FIELD AND HIGHER PATH LOSS

What about path loss?

Friis Transmission Equation

\[
\frac{P_r}{P_t} = \left( \frac{c}{4\pi R f} \right)^2 G_t G_r
\]

Path loss proportional to \( R^2 \)

From Keysight White Paper: OTA Test for Millimeter-Wave 5G NR Devices and Systems

<table>
<thead>
<tr>
<th>D (mm)</th>
<th>28 GHz</th>
<th>39 GHz</th>
<th>60 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.47</td>
<td>0.65</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>1.9</td>
<td>2.6</td>
<td>4</td>
</tr>
<tr>
<td>150</td>
<td>4.2</td>
<td>5.9</td>
<td>9</td>
</tr>
<tr>
<td>200</td>
<td>7.5</td>
<td>10.4</td>
<td>16</td>
</tr>
<tr>
<td>300</td>
<td>16.8</td>
<td>23.4</td>
<td>36.0</td>
</tr>
</tbody>
</table>

\( DFF = \frac{2D^2}{\lambda} \)

\( DFF = 2f \frac{D^2}{c} \)
### FR2 Measurement Challenges

#### HOW FAR IS THE FAR FIELD?

<table>
<thead>
<tr>
<th>D (cm)</th>
<th>Freq. (GHz)</th>
<th>Far field (m)</th>
<th>Path Loss (dB)</th>
<th>Freq. (GHz)</th>
<th>Far field (m)</th>
<th>Path Loss (dB)</th>
<th>Freq. (GHz)</th>
<th>Far field (m)</th>
<th>Path Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0.03</td>
<td>8.93</td>
<td>28</td>
<td>0.47</td>
<td>54.77</td>
<td>43</td>
<td>0.72</td>
<td>62.23</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>0.13</td>
<td>20.97</td>
<td>28</td>
<td>1.87</td>
<td>50.01</td>
<td>43</td>
<td>2.87</td>
<td>74.27</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>0.30</td>
<td>28.01</td>
<td>28</td>
<td>4.20</td>
<td>73.86</td>
<td>43</td>
<td>6.45</td>
<td>81.31</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>0.53</td>
<td>33.01</td>
<td>28</td>
<td>7.47</td>
<td>78.86</td>
<td>43</td>
<td>11.47</td>
<td>86.31</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>1.20</td>
<td>40.05</td>
<td>28</td>
<td>16.80</td>
<td>85.90</td>
<td>43</td>
<td>25.80</td>
<td>93.35</td>
</tr>
</tbody>
</table>

**TR 38.810 Table 5.3-1: DUT Categories**

<table>
<thead>
<tr>
<th>DUT category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Maximum one antenna panel with $D \leq 5$ cm illuminated by test signal at any one time</td>
</tr>
<tr>
<td>Category 2</td>
<td>More than one antenna panel $D \leq 5$ cm without phase coherency between panels illuminated at any one time</td>
</tr>
<tr>
<td>Category 3</td>
<td>Any phase coherent antenna panel of any size (e.g. sparse array)</td>
</tr>
</tbody>
</table>

Black Box testing
Three Common OTA Methods

**Suitability for MMW Test**

**Direct Far Field** simulates behavior of real-world operation—in which DUT receives just a plane-wave. Rayleigh ranged defined as $2D^2/\lambda$.

- Key questions: *what is D? How large is the required chamber?* Path loss.

**Near-field** test systems scan signals in the radiating near-field region and employ mathematical transforms to recover the far-field antenna pattern.

- Key issues: Device RX, RF parametric, and signaling tests challenging with today's technology.

**Compact Test Range** (CATR) or Indirect FF (IFF) uses reflectors to focus the RF energy into a plane wave—enables far-field measurements within a much shorter distance than would normally be required.

- Key issue: precision reflector design and fabrication required
- Key benefit: True far-field in compact footprint

- Key issues: Device RX, RF parametric, and signaling tests challenging with today's technology.
Compact Antenna Test Range (CATR)

**QUIET ZONE**

Paraboloid Reflector Section

Source

Plane wave in QZ

DUT

Path loss

Collimated* (Uniform) Beam Illuminates the DUT

- Power does **not** decrease with distance of DUT from reflector
- Amplitude and Phase Uniform over DUT
  Typical < 1dB Amplitude & < 10° Phase

*make (rays of light or particles) accurately parallel

Quiet Zone (QZ)

Quiet Zone diameter

Amplitude Taper & Ripple < ±0.5 dB

Phase Taper & Ripple < ±2°

Also referred to as *Indirect Far-Field (IFF)*
Common OTA Test Methods

Direct Far Field
- Simple design, mature
- Measurement flexibility
  - Antenna beam pattern characterization
  - Beamforming/beamsteering validation
  - RF parametric tests (if S/N high enough)
- How devices operate
- Subject to higher path loss
- Can get very large for smaller devices at mmWave frequencies
- Can be slow (mechanical motion), expensive

Indirect Far Field
- Measurement flexibility
  - Antenna beam pattern characterization
  - Beamforming/beamsteering validation
  - RF parametric tests
  - End-to-End performance (signaling)
- Small footprint, even for larger devices
- Lower path loss, better accuracy
- Slow (limited by mechanical motion)
- Expensive (slightly more than DFF)

Near-Field Scanning
- Small, lower cost (at mmWave?)
- Passive antenna;
  - Antenna beam pattern characterization
  - Beamforming/beamsteering validation
  - RF parametric tests (with phase recovery)
- Requires highly accurate positioners for mmWave
- Applicability to modulated signals
- Tx tests for active devices
- Rx tests
- Can be slow
Comparisons shown for high and low gain horn antennas

Comparisons show high degree of correlation between the different types of chambers

22 dB horn: Sage SAR-2013-34-S2
10 dB horn: Pasternack PE9851-10

**GREAT CORRELATION!**

Note: IFF positioner movement limited during measurement
### Measurement Systems for NR UE RF Test

<table>
<thead>
<tr>
<th>DUT Cat 1</th>
<th>DUT Cat 2</th>
<th>DUT Cat 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 cm</td>
<td>5 cm</td>
<td>3 G P P T R 3 8 . 8 1 0 S T U D Y O N T E S T M E T H O D S (O T A)</td>
</tr>
</tbody>
</table>

#### 3GPP TR 38.810 STUDY ON TEST METHODS (OTA)

<table>
<thead>
<tr>
<th>Single panel (Cat 1)</th>
<th>DFF (Direct Far Field)</th>
<th>IFF (CATR)</th>
<th>NF-TF (Near Field with Transform)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tx / Rx</td>
<td>✓</td>
<td>✓</td>
<td>• Tx Only</td>
</tr>
<tr>
<td>• High MU</td>
<td>✓</td>
<td>✓ Lowest MU</td>
<td>• N/A for RX tests</td>
</tr>
<tr>
<td>• Max D= 5cm</td>
<td>✓</td>
<td>✓ No Declaration (Blackbox)</td>
<td>• Max D= 5cm</td>
</tr>
<tr>
<td>• UE Declaration Required</td>
<td>✓</td>
<td></td>
<td>• UE Declaration required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Multi-panel with no coherence (Cat 2)</th>
<th>DFF (Direct Far Field)</th>
<th>IFF (CATR)</th>
<th>NF-TF (Near Field with Transform)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tx / Rx</td>
<td>✓</td>
<td>✓</td>
<td>Not Applicable/Approved</td>
</tr>
<tr>
<td>• Additional MU factor on Rx</td>
<td>✓</td>
<td>✓ Lowest MU</td>
<td></td>
</tr>
<tr>
<td>• Max D= 5cm</td>
<td>✓</td>
<td>✓ No Declaration (Blackbox)</td>
<td></td>
</tr>
<tr>
<td>• UE Declaration Required</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Multi-panel with coherence (Cat 3)</th>
<th>DFF (Direct Far Field)</th>
<th>IFF (CATR)</th>
<th>NF-TF (Near Field with Transform)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Applicable/Approved</td>
<td>✓</td>
<td>✓</td>
<td>Not Applicable/Approved</td>
</tr>
<tr>
<td>• Tx / Rx</td>
<td>✓</td>
<td>✓ Lowest MU</td>
<td></td>
</tr>
<tr>
<td>• No Declaration (Blackbox)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### MU = Measurement Uncertainty
The IFF test method based on compact antenna test range (CATR) uses a parabolic reflector to collimate the signals transmitted by the probe antenna.

Creates a far-field test environment in a much shorter distance and with less path loss than the DFF method.
### 3GPP NR gNB Conformance Tests

#### Chapter 6, 7, 8 Measurement Detail

#### 3GPP NR gNB Conformance Test Summary
(Conducted & Radiated)

<table>
<thead>
<tr>
<th>Chap 6, Tx Characteristics</th>
<th>Chap 7, Rx Characteristics Tests</th>
<th>Chap 8, Rx Performance Requirements Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Output Power</td>
<td>• Reference sensitivity level</td>
<td>• Performance requirements for PUSCH</td>
</tr>
<tr>
<td>• Output Power Dynamics</td>
<td>• Dynamic range</td>
<td>• With transmission precoding disabled</td>
</tr>
<tr>
<td>(RE Power Control DR / Total Power DR / ...)</td>
<td>• Adjacent Channel Selectivity (ACS)</td>
<td>• With transmission precoding enabled</td>
</tr>
<tr>
<td>• Transmit On/Off Power</td>
<td>• Blocking characteristics</td>
<td>• UCI multiplexed on PUSCH</td>
</tr>
<tr>
<td>(TX Off Power / TX Transient Period)</td>
<td>• Intermodulation characteristics</td>
<td>• Performance requirements for PUCCH</td>
</tr>
<tr>
<td>• Signal Quality</td>
<td>• In-channel selectivity</td>
<td>• Format 0 ~ 4</td>
</tr>
<tr>
<td>(Freq Error / EVM / Time Alignment Error / ...)</td>
<td>• Spurious emissions</td>
<td>• Multi-slot PUCCH</td>
</tr>
<tr>
<td>• Unwanted Emissions</td>
<td></td>
<td>• Performance requirements for PRACH</td>
</tr>
<tr>
<td>(Occupied BW / ACLR / Spurious / ...)</td>
<td></td>
<td>• False alarm probability and missed detection</td>
</tr>
<tr>
<td>• Transmitter Intermodulation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Summary**
- Requires time-aligned digitizers or digitizers with wide BW

<table>
<thead>
<tr>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tests are performed open loop</td>
</tr>
<tr>
<td>Tests require interfering signals</td>
</tr>
<tr>
<td>Performance metric = BLER (calculated by eNB)</td>
</tr>
</tbody>
</table>

**Summary**
- PUSCH tests performed closed loop (implies real-time sig gen) |
- Tests require fading of ‘wanted’ & AWGN |
- Performance metric = throughput (calculated by eNB)
### 3GPP gNB Transmitter Tests (Chap 6)

**BASIC CONFIG FOR MOST TESTS**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2, 6.3</td>
<td>OTA Base Station Output Power</td>
</tr>
<tr>
<td>6.4</td>
<td>OTA Output Power Dynamics</td>
</tr>
<tr>
<td>6.5.1</td>
<td>OTA Transmit OFF Power</td>
</tr>
<tr>
<td>6.5.2</td>
<td>OTA Transient Period</td>
</tr>
<tr>
<td>6.6.2</td>
<td>OTA Frequency Error</td>
</tr>
<tr>
<td>6.6.3</td>
<td>OTA modulation quality</td>
</tr>
<tr>
<td>6.6.4</td>
<td>OTA Time alignment error</td>
</tr>
<tr>
<td>6.7.2</td>
<td>OTA Occupied Bandwidth</td>
</tr>
<tr>
<td>6.7.3</td>
<td>OTA ACLR</td>
</tr>
<tr>
<td>6.7.4</td>
<td>OTA Out of band Emissions</td>
</tr>
<tr>
<td>6.7.5</td>
<td>OTA Transmitter Spurious Emissions</td>
</tr>
</tbody>
</table>

**Test Equipment**

- Conducted (cable)
- OTA

---

**gNB transmits appropriate Test Model (NR-TM)**

**FR2 DUTs will require OTA**

**gNB tests will likely follow the eNB very closely with changes added for FR2 OTA testing**

---

- 3GPP TS 38.141-1 (Conducted)
- 3GPP TS 38.141-2 (Radiated)
**OTA Power Measurements**

**TRP AND EIRP**

**Total Radiated Power (TRP) value** for the uniform measurement grid:

\[
TRP = \frac{\pi}{2NM} \sum_{i=1}^{N-1} \sum_{j=0}^{M-1} \left[ \text{EIRP}_\theta(\theta_i, \varphi_j) + \text{EIRP}_\varphi(\theta_i, \varphi_j) \right] \sin(\theta_i)
\]

where \(N\) is the number of angular intervals in the nominal \(\theta\) range from 0 to \(\pi\) and \(M\) is the number of angular intervals in the nominal \(\varphi\) range from 0 to \(2\pi\).

**EIRP** = Effective (or Equivalent) Isotropic Radiated Power (usually in dBi).

Measurement taken at one setting of \(\theta\) and \(\varphi\)

**Beam Position:**
- gNB – declared
- UE - beam locked

**BTS:** 3GPP TR37.842 & 843
**UE:** 3GPP TR38.810

**Spherical coordinate system**

**EIRP measured at two orthogonal polarizations**

**This case, SA can make power/spectrum measurement with the Total EIRP directly**
Example declarations of an OTA Active Antenna System (AAS) BS with multiple beam widths and beam steering capability;

- For the minimum beam width case: beam width (θ and ϕ) = 10°, maximum steering (θ and ϕ) = ±32.5°
- For the maximum beam width case: beam width (θ and ϕ) = 35°, maximum steering (θ and ϕ) = ±25°

Some Tx measurements made at peak beam position and/or max steering direction;
- Tx Power
- Freq Error
- EVM

Other measurements made at peak beam position and over grid (TRP);
- Tx Power
- ACLR
- Out-of-Band
What about those NR gNB Test Models?

**TS38.141-1 V1.0.0 SEC. 4.9.2 AND TS38.141-2 V1.0.0 SEC. 4.9.3**

- Duration: 1 radio frame (10 ms) for FDD, 2 radio frames (20 ms) for TDD
- Normal CP
- Virtual RB: Localized type

<table>
<thead>
<tr>
<th>Test Model</th>
<th>TS38.141-1</th>
<th>BS Output power, OBW, ACLR, OBUE, Spur, Intermod</th>
<th>BS output power, OBW, ACLR, OBUE, Spur</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR-TM1.1</td>
<td>4.9.2.2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NR-TM1.2</td>
<td>4.9.2.2.2</td>
<td>ACLR, OBUE</td>
<td></td>
</tr>
<tr>
<td>NR-TM2</td>
<td>4.9.2.2.3</td>
<td>Total power dynamic range (min pwr), 64QAM EVM, Freq error (min pwr)</td>
<td>Total power dynamic range (min pwr), 64QAM EVM, Freq error (min pwr)</td>
</tr>
<tr>
<td>NR-TM2a</td>
<td>4.9.2.2.4</td>
<td>Total power dynamic range, 256QAM EVM, Freq error</td>
<td></td>
</tr>
<tr>
<td>NR-TM3.1</td>
<td>4.9.2.2.5</td>
<td>Total power dynamic range (max pwr), 64QAM EVM, Freq error (max pwr)</td>
<td>Total power dynamic range (max pwr), 64QAM EVM, Freq error (max pwr)</td>
</tr>
<tr>
<td>NR-TM3.1a</td>
<td>4.9.2.2.6</td>
<td>Total power dynamic range (max pwr), 256QAM EVM, Freq error (max pwr)</td>
<td></td>
</tr>
<tr>
<td>NR-TM3.2</td>
<td>4.9.2.2.7</td>
<td>Freq error, 16QAM EVM</td>
<td></td>
</tr>
<tr>
<td>NR-TM3.3</td>
<td>4.9.2.2.8</td>
<td>Freq error, QPSK EVM</td>
<td></td>
</tr>
</tbody>
</table>
What about those NR gNB Test Models?

TS38.141-1 SECTION 4.9.2 NR TEST MODELS FOR FR1 TDD

Test model for FR1 TDD frame structure is defined.

We can generate this frame structure and populate PRB with any modulation type (eg 64 QAM)

<table>
<thead>
<tr>
<th>SCS [kHz]</th>
<th>Number of DL slots</th>
<th>Number of DL symbols in S slot</th>
<th>Number of UL symbols in S slot</th>
<th>Number of UL slots</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>60 (Note)</td>
<td>14</td>
<td>12</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: There are two S slots. First S slot has 12 DL symbols followed by 2 flexible symbols; second S slot has 6 flexible symbols followed by 8 UL symbols.

Reference:

LTE TDD
UL/DL Config = 2
Special Sf Config = 7
## What about those NR gNB Test Models?

**Test model for FR2 TDD frame structure is defined.**

We can generate this frame structure and populate PRB with any modulation type (eg 64 QAM)

### Table 6.1.2-1: Configurations of TDD gNB test models

<table>
<thead>
<tr>
<th>SCS [kHz]</th>
<th>Number of DL slots</th>
<th>Number of DL symbols in S slot</th>
<th>Number of UL symbols in S slot</th>
<th>Number of UL slots</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>60 (Note 1)</td>
<td>14</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>120 (Note 2)</td>
<td>29</td>
<td>10</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>240 (Note 3)</td>
<td>59</td>
<td>6</td>
<td>4</td>
<td>18</td>
</tr>
</tbody>
</table>

Note 1: There are two S slots. First S slot has 12 DL symbols followed by 2 flexible symbols; second S slot has 6 flexible symbols followed by 8 UL symbols.

Note 2: There are two S slots. First S slot has 10 DL symbols followed by 4 flexible symbols; second S slot has 12 flexible symbols followed by 2 UL symbols.

Note 3: There are three S slots. First S slot has 6 DL symbols followed by 8 flexible symbols; third S slot has 10 flexible symbols followed by 4 UL symbols.

---

**NR FR2 TDD SCS 120 kHz**

- D slots: 29
- U: 9

---

**NR FR2 TDD SCS 240 kHz**

- D slots: 59
- U: 18

---

**Reference:**

- **LTE TDD**
- UL/DL Config = 2
- Special Sf Config = 7

---

**Test model for FR2 TDD frame structure is defined.**

We can generate this frame structure and populate PRB with any modulation type (eg 64 QAM)
What about those NR gNB Test Models?

Used signal studio for 5G NR to generate a FR1 TDD NR-TM frame and filled all PRBs with 64QAM. Then used VSA to demodulate the frame.

<table>
<thead>
<tr>
<th></th>
<th>SCS [kHz]</th>
<th>Number of DL slots</th>
<th>Number of DL symbols in S slot</th>
<th>Number of UL symbols in S slot</th>
<th>Number of UL slots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

1 Frame = 10 ms = 10 slots
3GPP gNB Receiver Characteristics (Chap 7)

**Basic Test Config**

Conducted (cable)

Source generates required **Fixed Reference Channel (FRC)**

Receiver Sensitivity & Dynamic Range Tests

**3GPP TS 38.141-1** (Conducted)  
**3GPP TS 38.141-2** (Radiated)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3</td>
<td>OTA Reference Sensitivity Level</td>
</tr>
<tr>
<td>7.4</td>
<td>OTA Dynamic Range</td>
</tr>
<tr>
<td>7.5.1</td>
<td>OTA adjacent channel selectivity</td>
</tr>
<tr>
<td>7.5.2</td>
<td>OTA in-band blocking</td>
</tr>
<tr>
<td>7.6</td>
<td>OTA Out-of-band Blocking</td>
</tr>
<tr>
<td>7.7</td>
<td>OTA Receiver Spurious Emissions</td>
</tr>
<tr>
<td>7.8</td>
<td>OTA Receiver Intermodulation</td>
</tr>
<tr>
<td>7.9</td>
<td>OTA In-channel Selectivity</td>
</tr>
</tbody>
</table>

**EIS = Effective (or Equivalent) Isotropic Sensitivity**

gNB Calculates throughput based on received CRC

FR2 DUTs will require OTA

EIS = Effective (or Equivalent) Isotropic Sensitivity
3GPP gNB Receiver Characteristics (Chap 7)

**Additional Test Configs**

**Conducted (cable)**

- Frame trigger
- Source
  - Wanted Signal (FRC)
- gNB
  - Port 1
  - Port 2
  - Port 3
  - Port 4
  - Port n
- Source
  - Interference Signal #1
- Source
  - Interference Signal #2

**gNB Calculates throughput based on received CRC**

**FR2 DUTs will require OTA**

**Intermodulation Tests** (Blocking & Selectivity tests similar)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3    OTA Reference Sensitivity Level</td>
<td>EIS</td>
</tr>
<tr>
<td>7.4    OTA Dynamic Range</td>
<td>EIS</td>
</tr>
<tr>
<td>7.5.1  OTA adjacent channel selectivity</td>
<td>EIS</td>
</tr>
<tr>
<td>7.5.2  OTA in-band blocking</td>
<td>EIS</td>
</tr>
<tr>
<td>7.6    OTA Out-of-band Blocking</td>
<td>EIS</td>
</tr>
<tr>
<td>7.7    OTA Receiver Spurious Emissions</td>
<td>TRP</td>
</tr>
<tr>
<td>7.8    OTA Receiver Intermodulation</td>
<td>EIS</td>
</tr>
<tr>
<td>7.9    OTA In-channel Selectivity</td>
<td>EIS</td>
</tr>
</tbody>
</table>

3GPP TS 38.141-1 (Conducted)
3GPP TS 38.141-2 (Radiated)
Effective Isotropic Sensitivity (EIS) is the measured sensitivity in a single direction (fixed $\theta$ and $\varphi$). Usually expressed in dBm.

Total Isotropic Sensitivity (TIS) value for the uniform measurement grid:

$$TIS = \frac{2NM}{\pi \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \left[ \frac{1}{EIS_\theta(\theta_i, \varphi_j)} + \frac{1}{EIS_\varphi(\theta_i, \varphi_j)} \right] \sin \theta_i}$$

$$TIS = \frac{4\pi}{\int_0^{2\pi} \int_0^\pi \left[ \frac{1}{EIS_\theta(\theta, \varphi)} + \frac{1}{EIS_\varphi(\theta, \varphi)} \right] \sin \theta \, d\theta \, d\varphi}$$

This summation approximation is valid for TIS in the same way as for TRP.
Fixed Reference Channels (FRC) for gNB Rx Testing

Defined in Annex A.X in TS 38.141-1 & 38.141-2

Annex A (normative):
Reference measurement channels

A.1 Fixed Reference Channels for receiving and in-channel selectivity (QPSK, R, X)
The parameters for the reference measurement channels are specified in Table A.1-1.
The parameters for the reference measurement channels are specified in Table A.2-1.

Table A.1-1: FRC parameters for FR1 receiver sensitivity and in-channel selectivity

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcarrier spacing (GHz)</td>
<td>15</td>
<td>30</td>
<td>60</td>
<td>15</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Allocated resource blocks</td>
<td>25</td>
<td>11</td>
<td>11</td>
<td>106</td>
<td>51</td>
<td>24</td>
</tr>
<tr>
<td>CP-OFDM Symbols per slot (Note 1)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK</td>
<td>QPSK</td>
<td>QPSK</td>
<td>QPSK</td>
<td>QPSK</td>
<td>QPSK</td>
</tr>
<tr>
<td>Code rate (Note 2)</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
</tr>
<tr>
<td>Transport block CRC size (bits)</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Number of code blocks - C</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Coded block size</td>
<td>2166</td>
<td>1000</td>
<td>1000</td>
<td>4648</td>
<td>4376</td>
<td>216</td>
</tr>
</tbody>
</table>

Signal Studio Pro for 5G NR N7631C

FRC Quick Setup
3GPP gNB Receiver Performance Requirements (Chap 8)

Example 4x2 Test Case

Frame Trigger Pulse & 10 MHz ref

HARQ ACK/NACK real-time feedback

Wanted Signal Layer 1

Wanted Signal Layer 2

Signal Generator (Real-time)

3GPP Channel Models

Fader

Fader

Fader

Fader

Fader

Fader

Fader

Fader

Channel Emulator

AWGN

RF

RF

RF

RF

Port 1

Port 2

Port 3

Port 4

gNB Calculates throughput (based on CRC)
### 3GPP UE Conformance Test Requirements: Radiated

#### TS38.521-2 V.1.0.0 (V.2018-09) - DRAFT

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<th>Measurement</th>
<th>OTA</th>
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<td>UE maximum output power</td>
<td>Chan Power</td>
<td>EIRP, TRP</td>
</tr>
<tr>
<td>6.2.2</td>
<td>UE maximum output power reduction (MPR)</td>
<td>Chan Power</td>
<td>&lt;FFS&gt;</td>
</tr>
<tr>
<td>6.2.3</td>
<td>UE maximum output power with additional requirements</td>
<td>Chan Power</td>
<td>&lt;FFS&gt;</td>
</tr>
<tr>
<td>6.2.4</td>
<td>Configured transmitted power</td>
<td>Chan Power</td>
<td>EIRP, TRP</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Minimum output power</td>
<td>Chan Power</td>
<td>EIRP</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Transmit OFF power</td>
<td>Tx On/Off Power</td>
<td>TRP</td>
</tr>
<tr>
<td>6.3.3</td>
<td>Transmit ON/OFF time mask</td>
<td>Tx On/Off Power</td>
<td>EIRP</td>
</tr>
<tr>
<td>6.3.4</td>
<td>Power control</td>
<td>EIRP?</td>
<td></td>
</tr>
<tr>
<td>6.4.1</td>
<td>Frequency error</td>
<td>Mod Analysis</td>
<td>q &amp; j each</td>
</tr>
<tr>
<td>6.4.2.1</td>
<td>Error Vector Magnitude</td>
<td>Mod Analysis</td>
<td>q &amp; j each</td>
</tr>
<tr>
<td>6.4.2.2</td>
<td>Carrier leakage</td>
<td>Mod Analysis</td>
<td>EIRP?</td>
</tr>
<tr>
<td>6.4.2.3</td>
<td>In-band emissions (IBE)</td>
<td>Mod Analysis</td>
<td>&lt;FFS&gt;</td>
</tr>
<tr>
<td>6.4.2.4, 6.4.2.5</td>
<td>EVM equalizer spectrum flatness, EVM spectrum flatness for pi/2 BPSK with spectrum shaping</td>
<td>Mod Analysis</td>
<td>&lt;FFS&gt;</td>
</tr>
<tr>
<td>6.5.1</td>
<td>Occupied bandwidth</td>
<td>OBW</td>
<td>EIRP</td>
</tr>
<tr>
<td>6.5.2.1, 6.5.2.2</td>
<td>Spectrum emission mask Additional Spectrum emission mask</td>
<td>SEM</td>
<td>TRP</td>
</tr>
<tr>
<td>6.5.2.3</td>
<td>Adjacent channel leakage ratio</td>
<td>ACP</td>
<td>TRP</td>
</tr>
<tr>
<td>6.5.3</td>
<td>Spurious emissions</td>
<td>Spur Emissions</td>
<td>TRP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TS38.521-2</th>
<th>Receiver Test</th>
<th>Metrics</th>
<th>Assumed Link Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3</td>
<td>Reference sensitivity level</td>
<td>EIS CDF</td>
<td>Each beam peak search grid</td>
</tr>
<tr>
<td>7.4</td>
<td>Maximum input level</td>
<td>Beam peak</td>
<td>RX beam peak direction</td>
</tr>
<tr>
<td>7.5</td>
<td>Adjacent Channel Selectivity (ACS)</td>
<td>Beam peak</td>
<td>RX beam peak direction</td>
</tr>
<tr>
<td>7.6.2</td>
<td>In-band blocking</td>
<td>Beam peak</td>
<td>RX beam peak direction</td>
</tr>
<tr>
<td>7.6.3, 7.7</td>
<td>Out-of-band blocking and Spurious response</td>
<td>FFS</td>
<td>FSS</td>
</tr>
<tr>
<td>7.9</td>
<td>Receiver Spurious emissions</td>
<td>FFS</td>
<td>TX beam peak direction</td>
</tr>
<tr>
<td>7.10</td>
<td>Receiver image</td>
<td>FFS</td>
<td>FFS</td>
</tr>
</tbody>
</table>

FFS – For Further Study
3GPP UE Test Requirements: Radiated

**UE BEAMLOCK FUNCTION (UBF)**

Without UE Beamlock Function (UBF), the UE keeps forming the beam towards the SS

- Required for Spherical Coverage, TX & RX Beam Peak Searches, EIS, EIRP measurements

The **UBF** is intended for making the UE to lock the UE antenna pattern once it has formed a beam towards the base station (SS) direction

- **Required for TRP measurements**
- Recommended to prevent the beam from moving when performing measurements at low SNRs

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3GPP TS 38.521-2 (Radiated) – UE FR2

---

Activate Beamlock

Activate Beamlock Complete

3GPP TECHNOLOGIES

KEYSIGHT

UE

SS

SS

SS

SS
DIFFERENT QUESTIONS DIFFERENT APPROACHES

- How good is my antenna?
- Is my RF working?
- Is my chipset working?
- How good is my device?

• Meet QZ requirements
  • Speed of test
  • Accuracy

Connectivity to the modem
Replicate the spatial field

OTA: Workflows and Solutions

FF/IFF
Cable Replacement
Spatial OTA
Industry’s Most Complete mmWave OTA Portfolio

VALIDATE MMWAVE 5G DEVICES ACROSS WORKFLOW

RF/Antenna/RCT (RF performance)

- Indirect far field
- Module to full device testing
- 30 cm device size

Protocol/Functional/PCT (SW measurements)

- Direct far field
- Module to full device testing
- Light weight and bench top

End-to-End Mobility and Performance

- Direct far field
- Module to full device testing
- Supports fading models with Channel Emulator
Multi-Channel 5G Testbed for NR FR1 and FR2

Key Features

- 44 GHz Signal Creation / 110 GHz Analysis
- Multi-channel
- High Output Power
- 2 GHz signal Creation BW
- 110 GHz BW Demodulation Analysis
- Swept-tuned measurements to 110 GHz
- Import S-Parameters to de-embed test fixture

Test Signal
2x2 MIMO at 28 GHz

Device Under Test
Cross-polarized 28 GHz phased array

DC Power Analyzer

VXG
44 GHz Dual Ch. Source

UXR
110 GHz Oscilloscope

UXA
110 GHz Signal Analyzer
5G Non-Signaling mmWave Transceiver OTA Solution

COVERING THE 28 AND 39 GHZ MMWAVE BANDS

Wideband Transceiver Test Solution

- One Vector Signal Analyzer (VSA), one Vector Signal Generator (VSG) in 2U form factor saves precious rack space
- Simultaneous signal generation and analysis with independent frequency and power
- Two bi-directional IF ports
- Six RF ports for multiple device testing

mmWave Transceiver, 28 GHz and 39 GHz

- Tunable between 24 GHz and 43.5GHz bands
- EVM < 1% (depending on number of component carriers)
- Two full duplex ports

Software

- 5G NR and 5G TF measurements based on X-Series measurement applications integrated in the wideband transceiver
- Keysight Signal Studio applications for signal creation

mmWave RF Performance Test Solution

- Over-the-air (OTA) characterization and validation of mmWave device under test.
- EIRP, TRP, TRS, RF parametric measurements

Software

- Signal Studio Pro for 5G NR
- X-Series App 5G NR
- PathWave Test
5G Software: “First in 5G” & full use of “Automation”

ACROSS ENTIRE PRODUCT DESIGN CYCLE

PathWave is uniting these areas into a flow

EMERGING HW
EMERGING SW
KEY EXPERTISE