5G Boot Camp

PART 3:
7 KEY MEASUREMENT CHALLENGES AND CASE STUDIES

Keysight Technologies  AUG 2019

Philip Chang
7 Key Measurement Challenges

Signal Quality
*mmW, Waveform, Fidelity*

Lots of Channels
*MIMO/Beamforming*

Connect Design & Test
*Components, Systems*

Life Beyond Connectors
*Over-the-Air*

Performance on the Network
*Network Emulation*

Channel
*Characterizing & Emulating*

Field Testing and Drive Test

Protocol R&D

RF / RRM DVT

Functional KPI
## 3GPP UE & gNB Tx Conformance Test requirement docs

### 3GPP NR UE Tx test requirement

<table>
<thead>
<tr>
<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>
</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>
</tr>
<tr>
<td>Part 3: Range 1 and 2</td>
<td>TS38.101-3 v.15.2.0</td>
<td>TS38.521-3 v.1.0.0</td>
</tr>
<tr>
<td>Interworking operation with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other radios</td>
<td></td>
<td></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></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1: Conducted testing</td>
<td>TS38.104 v.15.2.0</td>
<td>TS38.141-1 v.1.0.0</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>
</tr>
</tbody>
</table>

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

Free-space Path Loss

\[ \text{Power}_{RX} = \text{Power}_{TX} + \text{AntGain}_{RX} + \text{AntGain}_{TX} - 20\log_{10}(4\pi R) - 20\log_{10}\left(\frac{f}{c}\right) \]

**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 \(\rightarrow\) 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**

* Image courtesy of Professor G. Rebeiz of U of Ca, SD
Far-Field Test Challenges with mmWaves

**LONGER FAR-FIELD AND HIGHER PATH LOSS**

What is $D$?

- Fastback Networks V1000
- Facebook Terragraph

Fraunhofer distance $[R]$

$R \geq \frac{2D^2}{\lambda}$

 Ideal Plane wave is at $\infty$

Path loss proportional to $R^2$

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

**Friis Transmission Equation**

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

**Path Loss**

<table>
<thead>
<tr>
<th>Far-Field Distance (m)</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**

- $DFF = 2D^2/\lambda$
- $DFF = 2fD^2/c$
## 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>80.81</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 ≤ 5 cm illuminated by test signal at any one time</td>
</tr>
<tr>
<td>Category 2</td>
<td>More than one antenna panel D ≤ 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>
# 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
Keysight CATR vs. Far Field Range*  

- 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

* http://allwavecorp.com/AntennaMeasurements.php

GREAT CORRELATION!
# Measurement Systems for NR UE RF Test

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

<table>
<thead>
<tr>
<th>DUT</th>
<th>Category</th>
<th>Measurement Configuration</th>
<th>DFF (Direct Far Field)</th>
<th>IFF (CATR)</th>
<th>NF-TF (Near Field with Transform)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 1</td>
<td>Single panel</td>
<td>Tx / Rx, High MU, Max D= 5cm, UE Declaration Required</td>
<td>✓ Tx / Rx ✓ Lowest MU ✓ No Declaration (Blackbox)</td>
<td>✓ Tx / Rx ✓ Lowest MU ✓ No Declaration (Blackbox)</td>
<td>• Tx Only • N/A for RX tests • Max D= 5cm • UE Declaration required</td>
</tr>
<tr>
<td>Cat 2</td>
<td>Multi-panel with no coherence</td>
<td>Tx / Rx, Additional MU factor on Rx, Max D= 5cm, UE Declaration Required</td>
<td>✓ Tx / Rx ✓ Lowest MU ✓ No Declaration (Blackbox)</td>
<td>Not Applicable/Approved</td>
<td></td>
</tr>
<tr>
<td>Cat 3</td>
<td>Multi-panel with coherence</td>
<td>Not Applicable/Approved</td>
<td>Not Applicable/Approved</td>
<td>✓ Tx / Rx ✓ Lowest MU ✓ No Declaration (Blackbox)</td>
<td>Not Applicable/Approved</td>
</tr>
</tbody>
</table>

**MU = Measurement Uncertainty**
# 3GPP gNB Conformance Tests (TS 38.141-1,2)

## Chapter 6, 7, 8 Measurement Details

### 3GPP NR gNB Conformance Test Summary

<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><strong>Output Power</strong></td>
<td>• Reference sensitivity level</td>
<td>• Performance requirements for PUSCH</td>
</tr>
<tr>
<td></td>
<td>• Dynamic range</td>
<td>• Multipath fading propagation conditions</td>
</tr>
<tr>
<td></td>
<td>• Adjacent Channel Selectivity (ACS)</td>
<td>• UL timing adjustment</td>
</tr>
<tr>
<td></td>
<td>• Blocking characteristics</td>
<td>• HARQ-ACK multiplexing for PUSCH</td>
</tr>
<tr>
<td></td>
<td>• Intermodulation characteristics</td>
<td>• High speed train conditions</td>
</tr>
<tr>
<td></td>
<td>• In-channel selectivity</td>
<td>• Performance requirements for PUCCH</td>
</tr>
<tr>
<td></td>
<td>• Spurious emissions</td>
<td>• ACK missed detection for single user PUCCH format 1a</td>
</tr>
<tr>
<td><strong>Summary</strong></td>
<td></td>
<td>• CQI missed detection for PUSCH format 2</td>
</tr>
<tr>
<td></td>
<td>• Requires time aligned digitizers</td>
<td>• HARQ-ACK multiplexing for multi user PUSCH format 1a</td>
</tr>
<tr>
<td></td>
<td>Or digitizers with wide BW</td>
<td><strong>Summary</strong></td>
</tr>
</tbody>
</table>

### 3GPP NR gNB Conformance Test Summary

**Conducted & Radiated**

<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>

<table>
<thead>
<tr>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 3 tests performed closed loop (implies real-time sig gen)</td>
</tr>
<tr>
<td>• Tests require fading of ‘wanted’ &amp; ‘interfering’ signals</td>
</tr>
<tr>
<td>• Performance metric = throughput (calculated by eNB)</td>
</tr>
</tbody>
</table>
**3GPP gNB Transmitter Tests (Chap 6)**

**BASIC CONFIG FOR MOST TESTS**

**gNB**
- Port 1
- Port 2
- Port 3
- Port 4

**Conducted (cable)**

**FR2 DUTs will require OTA**

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

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

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

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

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

**TRP AND EIRP**

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

\[
TRP = \frac{\pi}{2NM} \sum_{i=1}^{N-1} \sum_{j=0}^{M-1} \left[ EIRP_\theta(\theta_i, \phi_j) + EIRP_\phi(\theta_i, \phi_j) \right] \sin(\theta_i)
\]

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 \( \phi \) range from 0 to 2\( \pi \).

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

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

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

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

**Signal Analyzer**
**Power combiner**
**Anechoic Chamber**
**mmW**
**DUT**

This case, SA can make power/spectrum measurement with the Total EIRP directly

**Anechoic Chamber**
**DUT**
**Cross polarized horn antenna**

**DUT**
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 $(\theta \text{ and } \phi) = 10^\circ$, maximum steering $(\theta \text{ and } \phi) = \pm 32.5^\circ$
- For the maximum beam width case: beam width $(\theta \text{ and } \phi) = 35^\circ$, maximum steering $(\theta \text{ and } \phi) = \pm 25^\circ$

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 SECTION 4.9.2 NR TEST MODELS FOR FR1 TDD

Test model for FR1 TDD frame structure is defined but not the physical parameters.

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></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>8</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.
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>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>
</tbody>
</table>

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

**ADDITIONAL TEST CONFIGS**

Conducted (cable)

Intermodulation Tests
(Blocking & Selectivity tests similar)

Interference Signal#1

Interference Signal#2

Source

Wanted Signal (FRC)

Frame trigger

Source

∑

FR2 DUTs will require OTA

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 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>

OTA

Test Equipment

Transceiver Unit
Array 1 - P

Radio Distribution Network (RDN)

Antenna Array

NR BS

Radiating Interface Boundary (RIB)

5G Boot Camp: 7 Key Measurement Challenges and Case Studies
OTA Sensitivity Measurements

TIS AND EIS

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:

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

This summation approximation is valid for TIS in the same way as for TRP.

\[
TIS = \frac{4\pi}{\int_0^{2\pi} \int_0^\pi \left[ \frac{1}{EIS_{\theta}(\theta_1, \varphi)} + \frac{1}{EIS_{\varphi}(\theta_1, \varphi)} \right] \sin \theta_1 d\theta_1 d\varphi}
\]
Fixed Reference Channels (FRC) for gNB Rx Testing

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

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Annex A (normative):
Reference measurement channels

A.1 Fixed Reference Channels for receive and in-channel selectivity (QPSK, R

The parameters for the reference measurement channels are specified in table A.1.1 channel selectivity.

The parameters for the reference measurement channels are specified in table A.1.2 channel selectivity.

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>Network size</td>
<td>25</td>
<td>11</td>
<td>11</td>
<td>108</td>
<td>51</td>
<td>24</td>
</tr>
<tr>
<td>GF-OFDM Symbols</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>CP/OFDM Symbols</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Code rate (Note 2)</td>
<td>7/3</td>
<td>7/3</td>
<td>7/3</td>
<td>7/3</td>
<td>7/3</td>
<td>7/3</td>
</tr>
<tr>
<td>Transport block</td>
<td>216</td>
<td>1000</td>
<td>1000</td>
<td>4648</td>
<td>4376</td>
<td>216</td>
</tr>
<tr>
<td>CRC size</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

Signal Studio Pro for 5G NR N7631C

FRC Quick Setup

---

5G Boot Camp: 7 Key Measurement Challenges and Case Studies
3GPP gNB Receiver Performance Requirements (Chap 8)

**EXAMPLE 4x2 TEST CASE**

- **Wanted Signal**
  - BBG (Real-time)
  - BBG (ARB)
  - BBG (ARB)
  - BBG (ARB)

- **Interferer #1**
  - BBG (ARB)

- **Interferer #2**
  - BBG (ARB)

- **Interferer #3**
  - BBG (ARB)

**UE Emulation (Layer 1 with Transport Channel Coding)**

- **2x simultaneous real-time feedback (Timing Adjustment & HARQ ACK/NACK)**

- **BW TBD** (likely 100 MHz for FR1 & FR2 - Designers may want 400 MHz, regardless of 3GPP Spec)

**3GPP Channel Models**

- **RF**
- **AWGN**

**gNB**

- Port 1
- Port 2
- Port 3
- Port 4

- **gNB Calculates throughput (based on CRC)**

- **FR2 DUTs will require OTA**
- **Legacy LTE supports 8x8 spatial multiplexing (not required in conformance test but of interest in R&D)**
- **Depending on gNB capability, some tests require: 1x2, 4x2, 2x2, 3x2, 3x4, 3x8**
# 3GPP UE Conformance Test Requirements: Radiated

<table>
<thead>
<tr>
<th>TS38.521-2</th>
<th>Transmitter Test</th>
<th>Measurement</th>
<th>OTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.1</td>
<td>UE maximum output power</td>
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### 3GPP TS 38.521-2 (Radiated) – UE FR2

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<tr>
<td>7.10</td>
<td>Receiver image</td>
<td>FFS</td>
<td>FFS</td>
</tr>
</tbody>
</table>

FFS – For Further Study
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
Keysight OTA Solutions for mmWave UE Test

FROM R&D TO CONFORMANCE TO CARRIER COMPLIANCE

Rack Mount Test Chamber (RMTC)
- Fits in 19" rack
- 5-cm QZ size
- Single AoA
- Direct far-field
- 1x dual-polarized probe

Light weight, Cable replacement

Compact Antenna Test Range (CATR) or IFF
- Multiple sizes
- Single AoA
- Indirect Far-field
- 1x dual polarized probe

Black-box testing - 3GPP Approved Solution for RF Test

2D MPAC
- Multiple AoA
- Far-field
- 3-4 dual polarized probe
- 45° 2D arch
- Benchtop installation

Antenna / RF Parametric / TRP & TIS / Functional (incl. beam tracking) / Protocol testing / Throughput (clean channel)

3D MPAC
- Multiple AoA
- Far-field
- 4 out of 6 X-polarized probes
- 180° basic 3D or sectorized

Performance test (with fading – 38.901) / RRM (HO & Throughput) / Virtual drive test / Beam Management

UE Calibration / Array Calibration / Functional / Protocol Signaling / Performance / Demod tests

5G Boot Camp: 7 Key Measurement Challenges and Case Studies
Multi-Channel 5G Testbed for gNB

3GPP CONFORMANCE READY – HIGH PERFORMANCE

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
7 Key Measurement Challenges

Signal Quality
mmW, Waveform, Fidelity

Lots of Channels
MIMO/Beamforming

Connect Design & Test
Components, Systems

Life Beyond Connectors
Over-the-Air

Performance on the Network
Network Emulation

Channel
Characterizing & Emulating

Field Testing and Drive Test

Protocol R&D RF / RRM DVT Functional KPI
Get the fastest path to 5G Solutions

TARGETING CHIPSET AND DEVICE WORKFLOW

5G Interactive R&D Solutions
- Protocol R&D
- RF Toolset
- Functional KPI
- May’18 → Sep’18 → Dec ‘18

5G Device Acceptance Solutions
- Protocol Conformance
- RF/RRM Conformance
- Carrier Acceptance
- Oct-18 → Dec-18 → Future

5G MFG Solutions
- Manufacturing
- Apr ‘18

Keysight 1st Solutions across the entire device workflow

- Network Emulator
- Channel Emulator
- mmWave OTA Solutions
- Seamless RF and Protocol Solution
- Accumulates engineering know-how
- Embodies ecosystem insights
- Spans ecosystem with continuous releases

EXM – E6640A
UXM 5G – E7515B
PROPSIM
CIU
RMTC / CATR / MPAC
Non-Signaling Solution

... ACCELERATE TOWARDS NEW 5G DEVICES
Early protocol development while keeping up with evolving 5G standards:

- Progress stack and gain insights to optimize performance
- Customize scripts, automate efficiently, and debug quickly
- Leverage work across workflow stages, stay current with standards cost effectively

Key Features:

- Earliest availability of new 5G features
- Replicate desired network behavior whilst reducing test complexity with Built-in Protocol State Machine and Dynamic Control Points
- L1/L2 parameter change without programming
- Flexible automation and logging
- Results viewer

Sub-6 GHz and mmWave - Conducted and OTA
Modify network behaviour easily

**5G PROTOCOL R&D TOOLSET**

- Allow dynamic L1/L2 parameter changes without the need for programming
- Very useful in early development testing of prototypes
## 5G logging

### 5G PROTOCOL R&D TOOLSET

- Displays all layers of the protocol stack; PHY, MAC, RLC, RRC, PDCP
- Filtering allows the user to view the data of interest
- Advanced search features and bookmarks make debugging easier
- User friendly as all information needed is available in one view

### Log Viewer

<table>
<thead>
<tr>
<th>Summary</th>
<th>Log Elements</th>
<th>KPI View</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Type</td>
<td>Protocol</td>
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<td>66209</td>
<td>Development AP</td>
<td>Property Set</td>
</tr>
<tr>
<td>66210</td>
<td>Development AP</td>
<td>Property Set</td>
</tr>
<tr>
<td>66211</td>
<td>Development AP</td>
<td>Property Set</td>
</tr>
<tr>
<td>66212</td>
<td>Development AP</td>
<td>Property Set</td>
</tr>
<tr>
<td>66213</td>
<td>Development AP</td>
<td>Property Set</td>
</tr>
</tbody>
</table>

- **BCH BCI-Message**
  - Source: Protocol IBC, Version IBC, Jan 2018
  - Record: BCH BCI-Message
  - Fields:
    - BCH BCI-Message
5G Device End-to-End Workflow

R&D Challenges – RF DVT

5G Interactive R&D

5G Device Acceptance

More RF bands, wider bandwidths, and beamforming;
• Wideband calibration and verification
• New waveforms, flexible numerology
• Beamforming & beam management
• More band combination complexity

DVT = Design Validation Test

Key Features:
✓ 5G NR support
✓ RF Test Application
✓ Automation & Scripting
✓ Pre-conformance ready
✓ Traceability to conformance

Sub-6 GHz and mmWave - Conducted and OTA
Establish a 5G NR Call

SINGLE CELL AND CARRIER AGGREGATION

Main Cell (LTE)

Secondary Cells (NR)

Frequency range, band, bandwidth...

Power, Timings, Antenna Ports

Note: Maximum number of Cells may depend on technology, bands and HW configuration
Establish a 5G NR Call

**BEAM CONFIGURATION**

Select SSB position, FR1 and FR2 has different bitmaps

FR1, \( L = 8 \)

FR2, \( L = 64 \)

SSB includes 1 PSS, 1 SSS and 2 PBCH OFDM symbols the random access, transmitted over the same single antenna transmission scheme.
Establish a 5G NR Call

**PHYSICAL LAYER PARAMETERS**

Define DL and UL Bandwidth parts; starting CRB, duration expressed in PRBs, Sub Carrier Spacing, Code Prefix.

Each BWP consist on a group of contiguous PRBs.
Establish a 5G NR Call

PHYSICAL LAYER PARAMETERS

HARQ, DL and UL channels and signals configuration
Establish a 5G NR Call

SCHEDULING

5G Boot Camp: 7 Key Measurement Challenges and Case Studies
RF test on-a-call

TRANSMITTER

Channel Power

Occupied Bandwidth

Modulation Parameters

Power Statistics

Spectrum Emission Mask

IQ Waveform
Rx Measurements

- Cell Power Selection
- Sensitivity through ACK/NACK count
- BLER is the Rx performance metric
- Throughput
RF Automation Toolset

**Test Campaign**
- Add test cases into one Test Mode Condition
- Add multi Test Mode Condition into Test Plan

**Test Condition**
- Set measurement Band, SCS, Bandwidth and Channel
- Load 3GPP default H/M/L channel from database

**Test Cases**
- All test cases refer to 3GPP 38.521 chapter 6 and chapter 7
- Load 3GPP default test condition like RB Allocation, OFDM type and MCS.

**Test Log Panel**
- Error information and SCPI command Logs

**Test Result List**
- Result display with P/F indication
- Automatically export result to csv and Excel files.

**Others**
- Support report in text and CSV format
- Support adb command for flight mode
RF Automation Toolset

REPORTING TOOLS

- Real-time measurements (via X-Apps), logs and results are visible in the user interface

- Campaign summary reports may be generated in .csv and .xlsx formats
Support for sustained maximum E2E throughput, meet power consumption goals;

- Stress test the device at maximum E2E data throughput
- Benchmark battery life performance for different 5G use cases

**KPI = Key Performance Indicators**

**Key Features:**

- Easy to use GUI enables complex tests without the need to define protocol scripts
- Network configurations optimized to measure device performance
- Throughput, Battery life, Beam management
- Flexible automation, including use of external measurement equipment
- Simple Test case development
- Use results viewer for off line analysis

Sub-6 GHz and mmWave - Conducted and OTA
5G Device End-to-End Workflow

**DEVICE ACCEPTANCE**

5G Interactive R&D

- Protocol
- RF Toolset
- Functional KPI

5G Device Acceptance

- Protocol Conformance
- RF/RRM Conformance
- Carrier Acceptance

**Protocol**

- Protocol R&D
- TTCN-3 Test Suite
- Test Spec TS 38.523-1
- TTCN-3 Editor / Viewer
- PCT Test Manager
- Log Viewer

**RF/RRM**

- RF Rx/TX Test cases
- Test Spec 38.521-4
- Future
- Radio Resource Management (RRM)
- RCT Test Manager
- Sequencer
- Log Viewer

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5G Boot Camp: 7 Key Measurement Challenges and Case Studies
Keysight 5G NR Conformance Test Platform

TP168 INTRODUCED BY AUGUST 2018 IN GCF
What are your mm-Wave OTA testing needs?

5G DEVICE END-END SOLUTIONS

- RF/Antenna
- Protocol/Functional Single Link
- Beamforming with Clean channel
- Mobility and Performance

- CATR
- RMTC
- 2D MPAC
- 3D MPAC
5G NES Hardware Components

3 KEY BUILDING BLOCKS

UXM 5G Wireless Test Platform (E7515B)
- <6GHz Frequency range
- Scalable bandwidth 8Tx/4Rx @800MHz, 4Tx/2Rx @1600MHz
- Integrated RFIO + Internal fading
- Support for RF, IF, Host and BBIQ interfaces (slow and full rate)
- Support for 10GbE connectivity

Common Interfacing Unit (E7770A)
- Same unit for both PROPSIM CE and UXM 5G
- Supports up to 8x heads, with scalability for more
- Flexibility to add new heads to support new bands
- Supports high IF connection (6-12 GHz)

mmWave Transceiver for 5G (RRH)
- Supports 28, 39 and 40GHz bands
- Compact, bi-directional
Questions and Resources
WHERE TO GO FOR HELP

www.keysight.com/find/5GNR

- Simulation
  - www.keysight.com/find/Systemvue

- Signal Generation:
  - www.keysight.com/find/N7631C
  - www.keysight.com/find/N5182B
  - www.keysight.com/find/N9383A
  - www.keysight.com/find/M8190A
  - www.keysight.com/find/M8195A

- Signal Analysis:
  - www.keysight.com/find/89601B
  - www.keysight.com/find/N9085E
  - www.keysight.com/find/N
  - www.keysight.com/find/M9393A
  - www.keysight.com/find/PXA
  - www.keysight.com/find/UXA

- Channel Emulation:
  - www.keysight.com/find/Propsim

- DVT and Manufacturing:
  - www.keysight.com/find/E6640A
  - www.keysight.com/find/M9410A
  - www.keysight.com/find/M9411A
  - www.keysight.com/find/S9100A

- Contact your local Field Engineer for:
  - gNB Emulator for UE Testing: (UXM 5G – E7515B)
  - Test chambers
  - mmWave extenders (CIU and RRH)

- Field Testing:
  - www.keysight.com/find/Fieldfox
  - www.keysight.com/find/NEMO

5G Boot Camp presentations available from:
www.keysight.com/find/5GBootCampPresentations