# RF Test Strategies and Solutions for 5G Millimeter Wave Devices

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**Teradyne**

TestConX中国 China

Virtual ▪ October 27-29, 2020

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# What Does it Take to Build a 5G Network?

## What Does it Take to Build a 5G Network?


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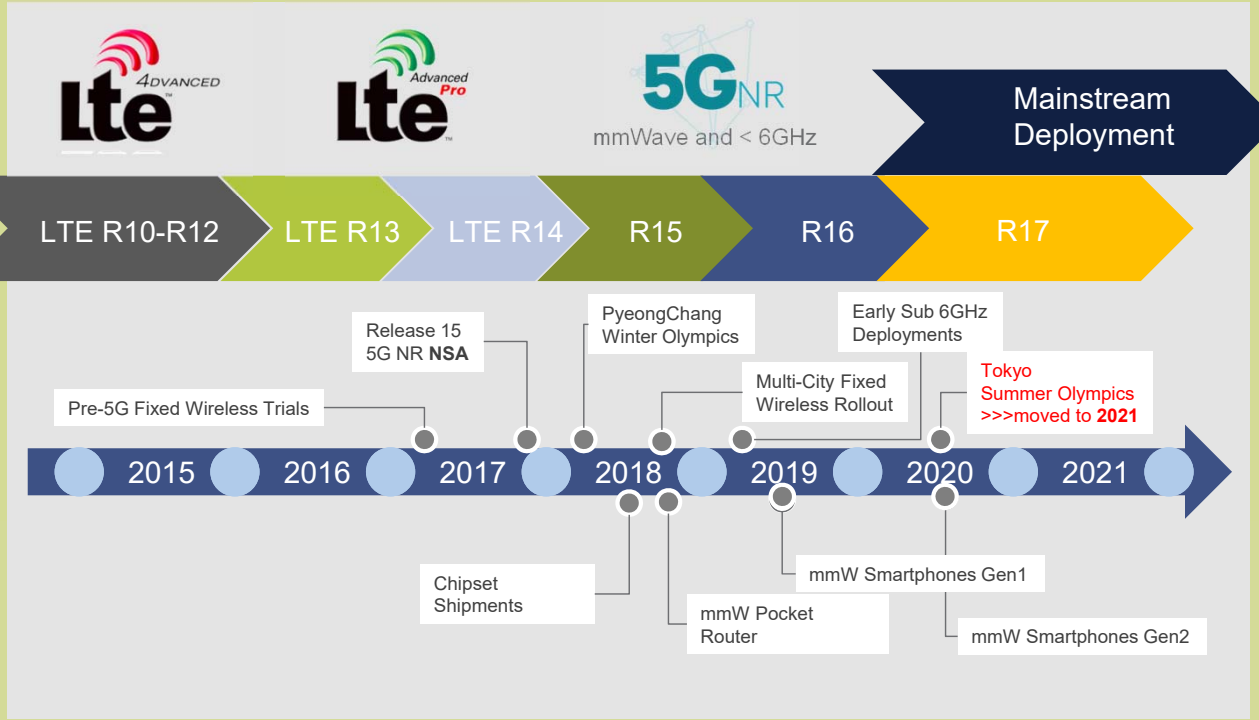
## 3GPP 5G NR Standard Development

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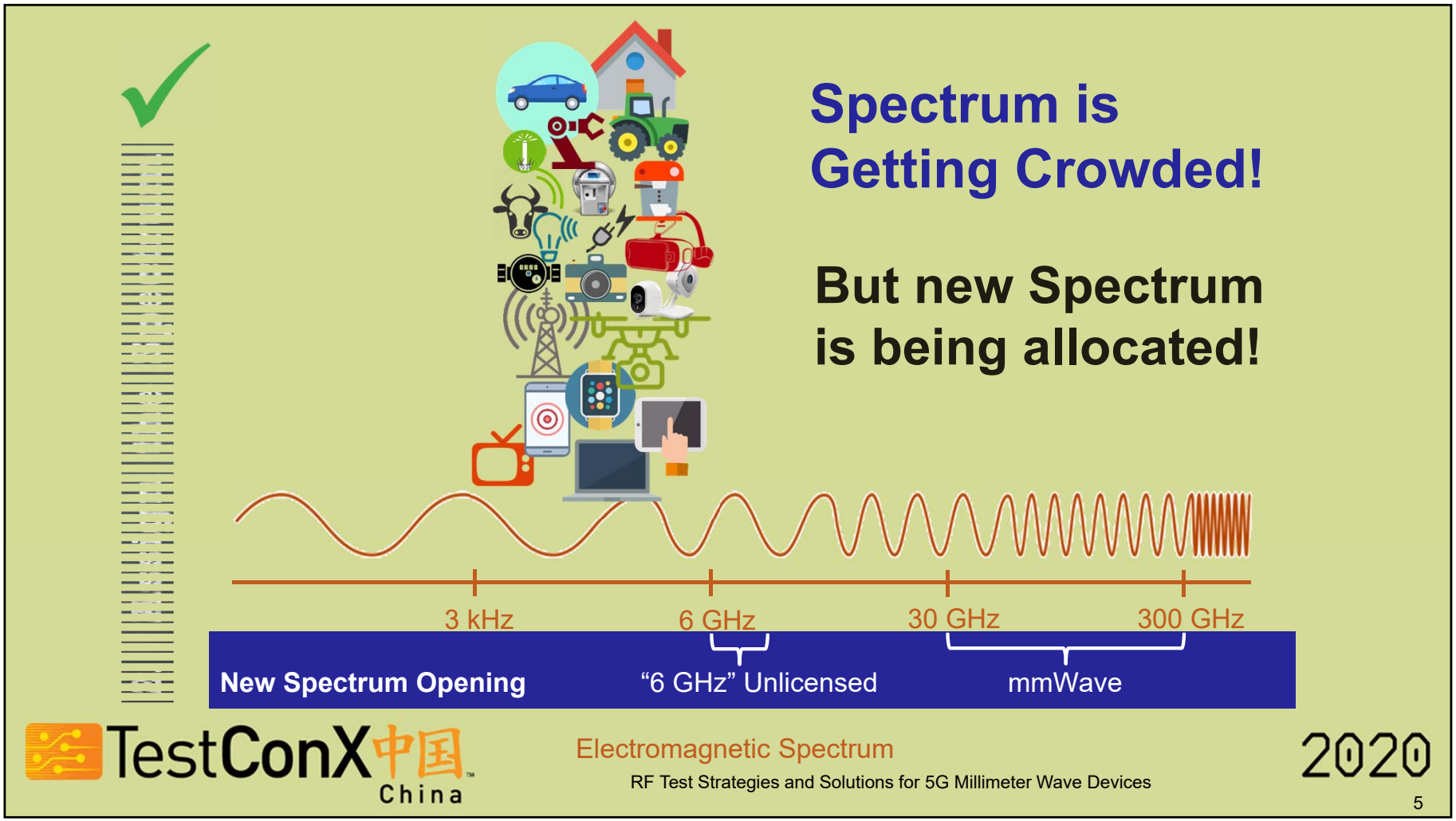
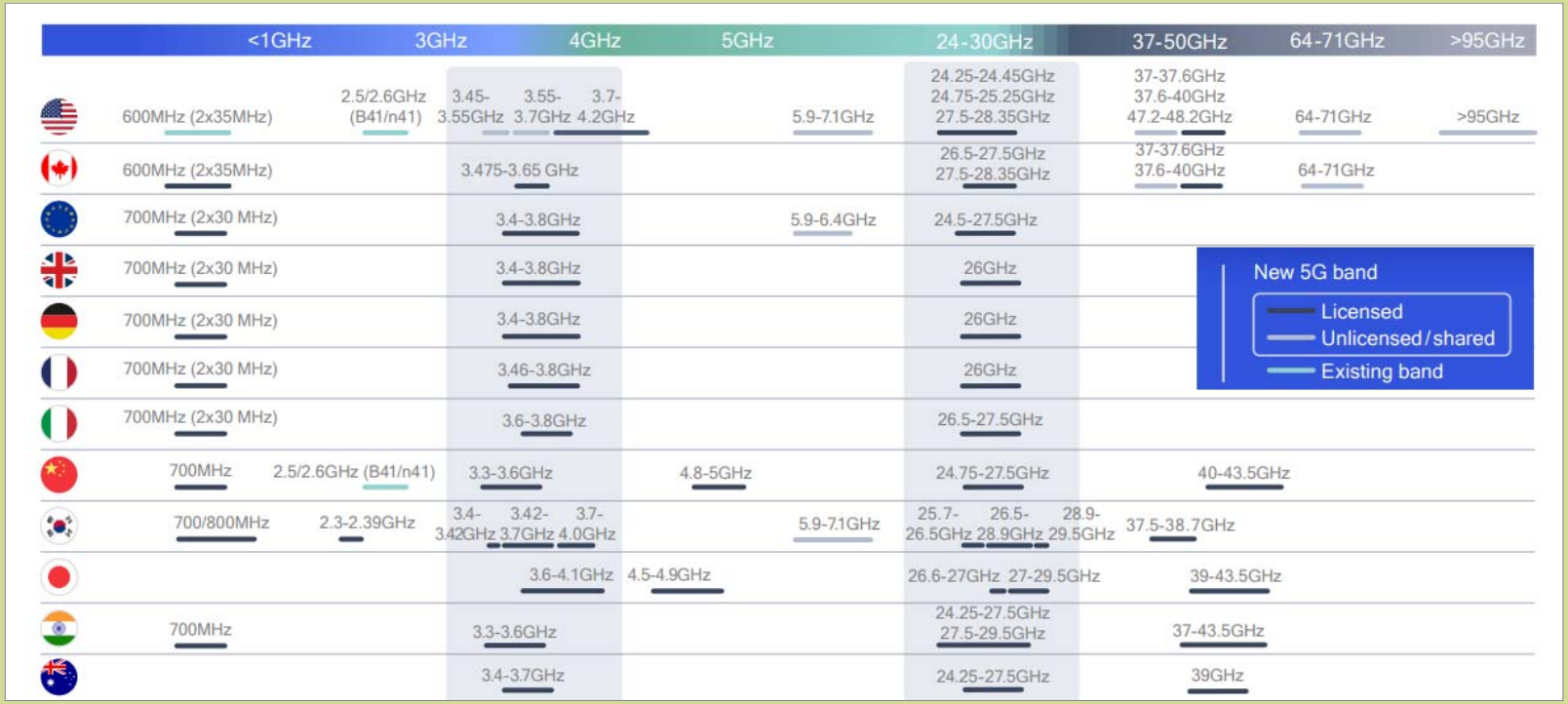


# Global snapshot of allocated/targeted 5G spectrum




Source: https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf (April 2020)

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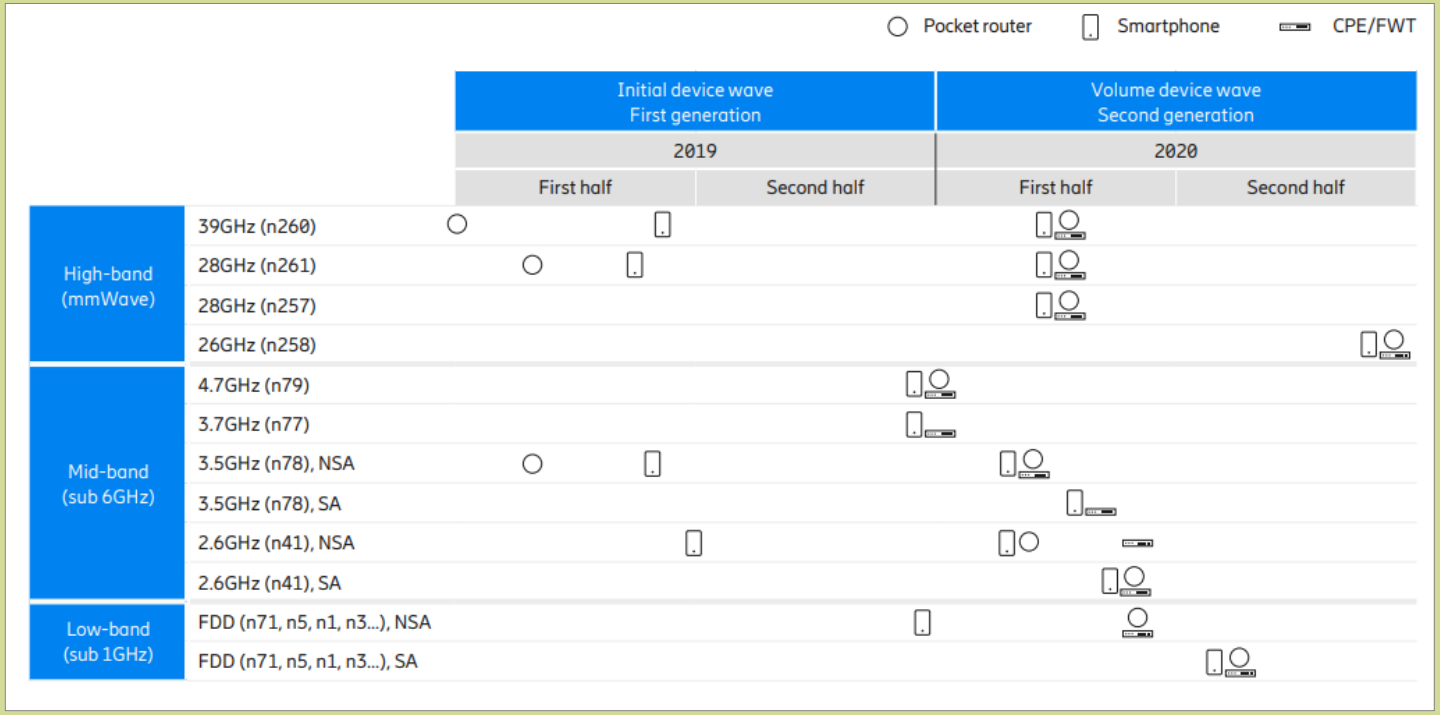
# 5G Device Availability Timeline




Source: Ericsson's Mobility Report June 2020

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## Examples of Mobile 5G Device Announcements


Moto Z3 w/ 5G mod


Samsung Galaxy S10 5G


Samsung Galaxy Fold


LG V50 ThinQ 5G


ZTE Axon 10 Pro 5G



iPhone 12 Pro
iPhone 12 Pro Max
iPhone 12
iPhone 12 mini


Huawei Mate X


Xiaomi Mi Mix3 5G


OPPO Reno 5G

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# Examples of Mobile Hotspot and CPE Devices Announcements


Netgear Nighthawk
Mobile Hotspots


Huawei
Mobile Hotspots


Inseego
Mobile Hotspots

Samsung
CPE


Huawei CPE Pro 5G

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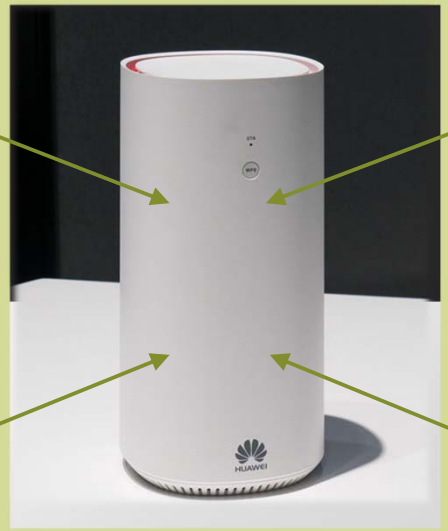
# 5G CPE Moves the Data Pipe "Bottleneck"

New Wireless Technology:

3GPP NR
(mmWave or sub-6 GHz)



High Performance Wi-Fi Access Point:

802.11ac → 802.11ax

More antennas,
More bands,
Carrier-grade quality

Various Additional Connectivity Standards:

Bluetooth, Zigbee, etc.

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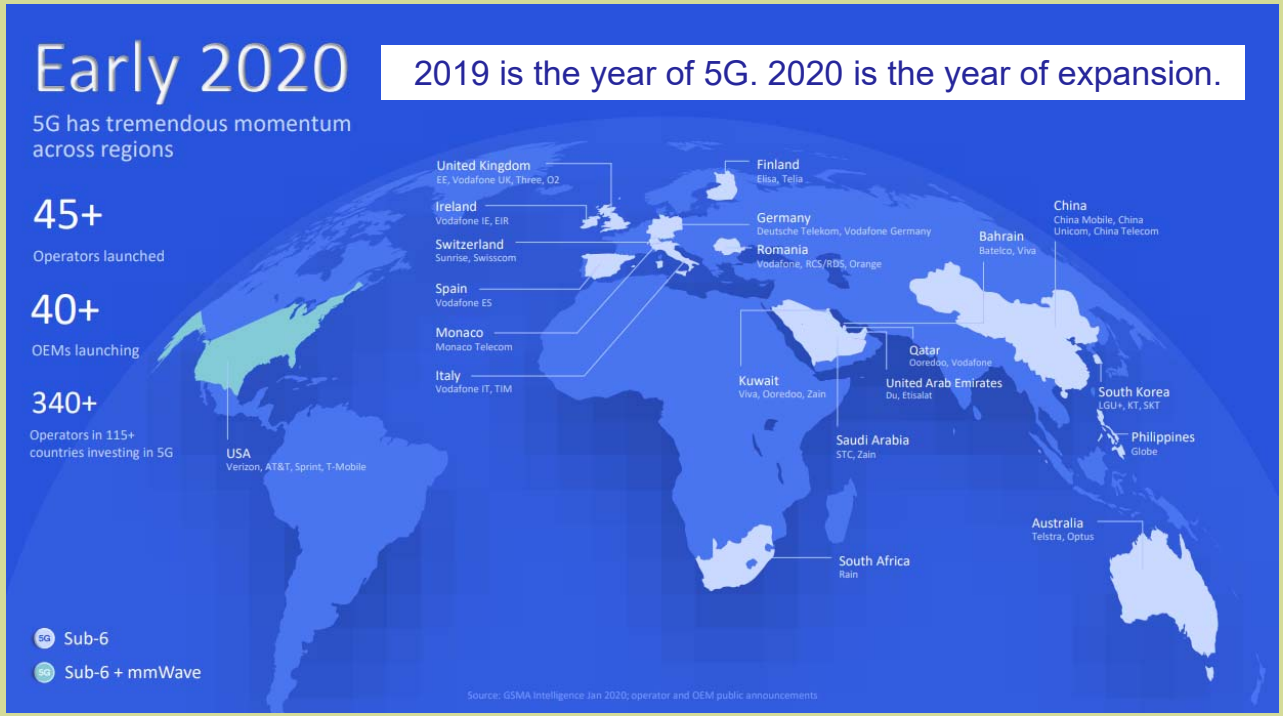
# Global 5G Infrastructure Deployments




Source : https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf (April 2020)

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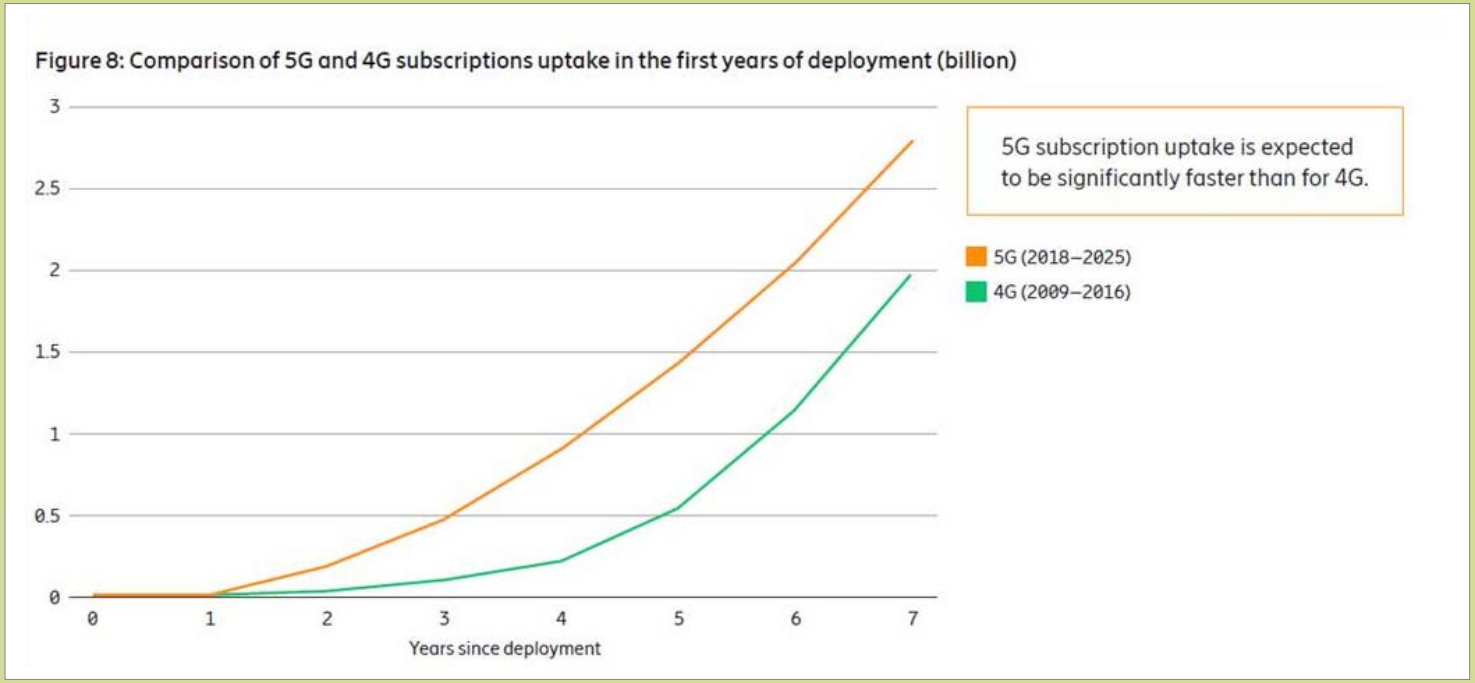
## 5G subscription uptake much faster than 4G!




Source: Ericsson's Mobility Report June 2020

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# 5G Capacity Enablers: mMIMO, Small Cells an mmWave

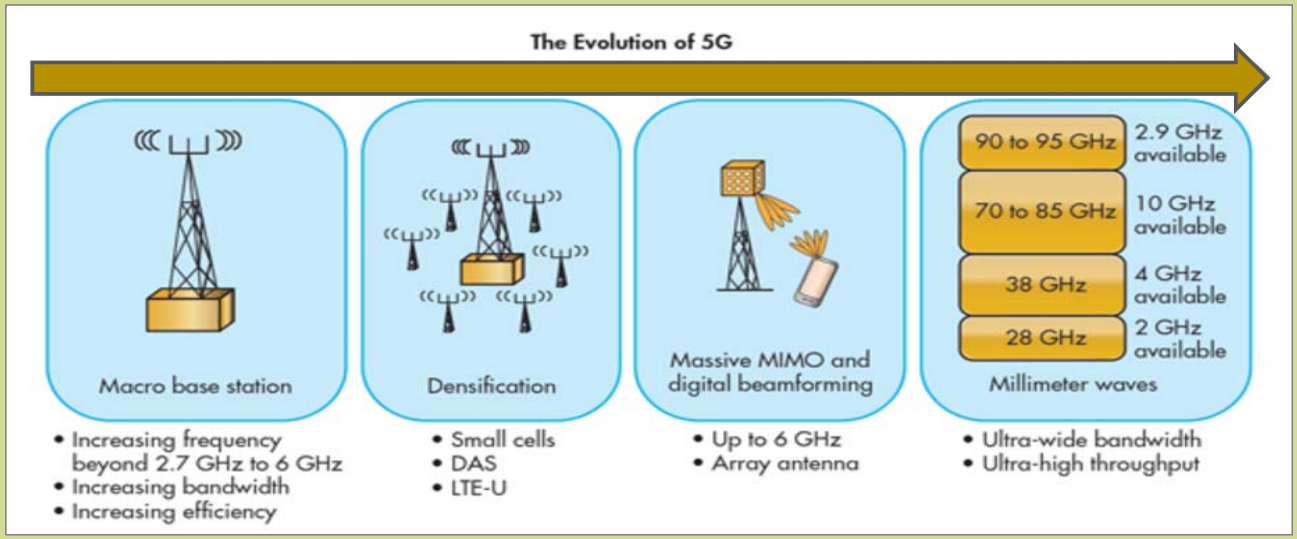
5G Channel Capacity (bps) = (BW)* $\log_2$ (1 + SINR[1])

**mmWave Value Proposition:**

Much higher BW than Sub 6 GHz

**Small Cells Value Proposition:**

Higher SINR with Massive MIMO + Beamforming at < 6GHz and mmWave




[1] SINR: signal to interference and noise ratio

Source: https://www.qorvo.com/design-hub/blog/small-cell-networks-and-the-evolution-of-5g

x1600 times gain in capacity expected with Small Cells Densification

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## What Does it Take to Build a 5G Network?


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# 5G NR Key Parameters

| Item | Frequency Range 1 (FR1) | Frequency Range 2 (FR2) |
|---|---|---|
| **Known As** | Sub 6 GHz | mmWave |
| Frequency Range | 450 MHz - 6000 MHz | 24250 MHz - 52600 MHz |
| Duplex Mode | FDD, TDD | TDD |
| Subcarrier Spacing | 15, 30, 60 KHz | 60, 120 KHz |
| Bandwidth | 5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz | 50, 100, 200, 400 MHz |
| MIMO | DL: 8x8 UL: 4x4 | DL: 2x2 UL: 2x2 |
| MIMO Method | Spatial Multiplexing for higher Throughput | Beamforming for better SNR |
| Radio Frame Duration | 10ms | |
| Subframe Duration | 1ms | |
| Modulation | pi/2-BPSK, QPSK, 16QAM, 64QAM, 256QAM | pi/2-BPSK, QPSK, 16QAM, 64QAM |
| Access | DL: CP-OFDM UL: CP-OFDM, DFT-s-OFDM | |
| Carrier Aggregation | 16 carriers maximum | |
| Channel Coding | Polar Codes, LDPC Codes | |

Higher Frequencies

Higher Bandwidth

**Maximum CC (Component Carrier) bandwidth is 100 MHz for FR1 and 400 MHz for FR2: *a 5x to 20x improvement over 4G LTE!***

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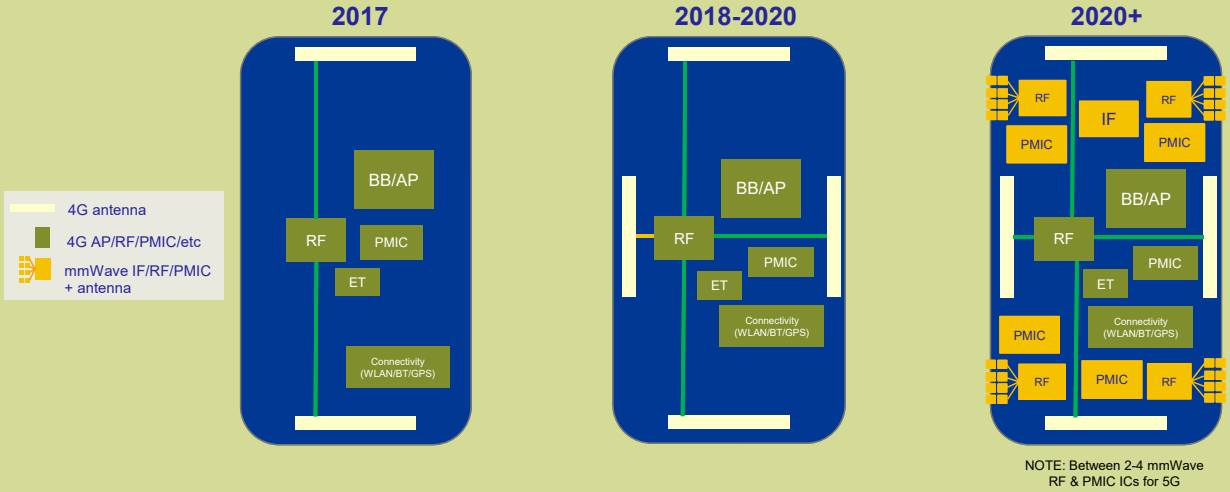
# Anatomy of a Smartphone – The Impact of 5G




NOTE: Between 2-4 mmWave RF & PMIC ICs for 5G

| | | | |
|---|---|---|---|
| **MIMO** | 2x2 MIMO | 4x4 MIMO | 4x4 MIMO + Patch Arrays for mmWave |
| **Data rates** | 450-600 Mbps | Up to 1,000 Mbps | 10,000 Mbps |
| **Carrier Frequency** | < 6GHz Frequencies | < 6GHz Frequencies | < 6GHz + mmWave Frequencies |
| **CC Bandwidth** | Up to 20MHz CC bandwidth | Up to 100MHz CC bandwidth | Up to 100MHz CC bandwidth |
| **Radio "Cores"** | 3DL/2UL | 6DL/2UL | 9DLP (Component Carriers) |
| **Silicon Count** | 5-7 Major ICs (*depending on AP/BB integration*) | 5-7 Major ICs (*depending on AP/BB integration*) | **9-15 Major ICs** (*depending on AP/BB integration & mmWave RF devices*) |

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*5G complexity adds more risk of field failures*

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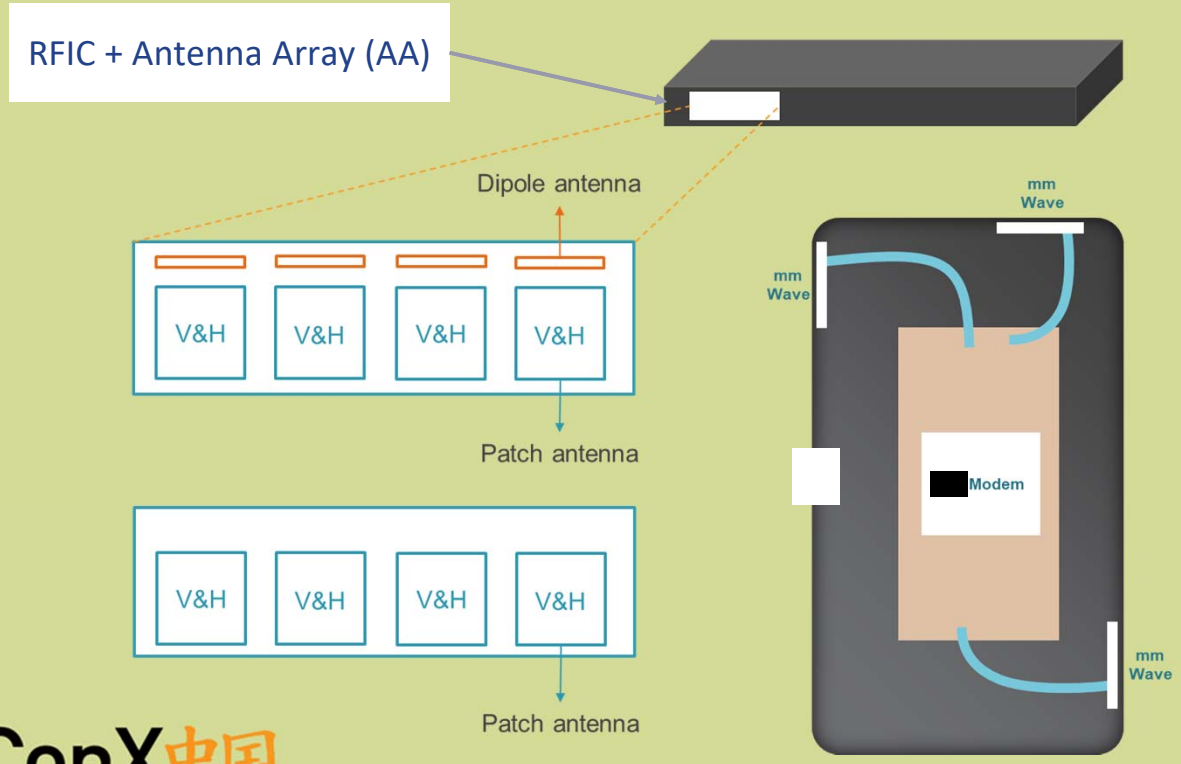
## 5G millimeter wave Devices Require Some Form of "over the air" (OTA) Test as the Antennas are Packaged with the RF IC

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# Why Test?

If 5G fails, your brand fails.

- **5G mmWave** devices are in the very early product life cycle stage and performance risks need sound test strategies.
- **5G mmWave premium phones** will demand **0 DPPM** quality levels – can't have 5G silicon failure in the field.
- Incumbent smartphone manufacturers **need to establish a reliable 5G brand** as Chinese vendors rise in smartphone market share
- **A high-quality brand strategy** requires more functional tests at probe and module insertions
- **Poor upstream** module (in particular, AiP), sub-assembly and final product **OTA yields** will also drive more functional test to eliminate upstream assembly scrap.
- Characterization tests will uncover **failure mechanisms**.
- **5G use cases that drive** volume and **performance** will in turn drive more device functional testing.
- Any "emergency" massive field failures will require functional-test-ready ATE on site

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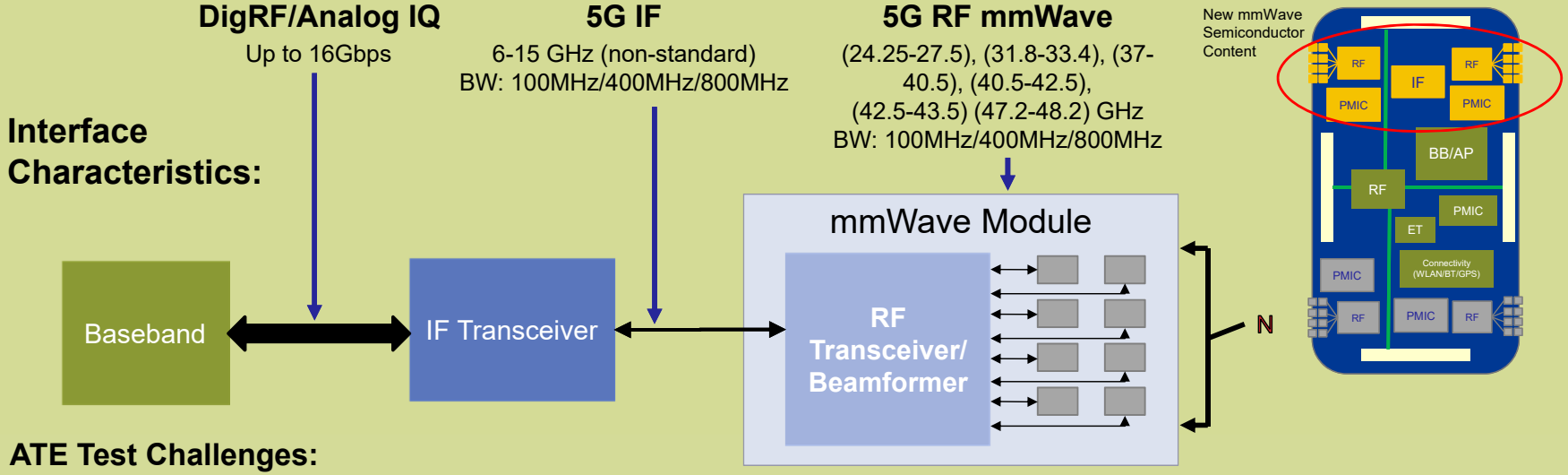
# 5G mmWave is Changing Traditional Cell Phone Architecture and Test Needs




**ATE Test Challenges:**

- Use of antenna arrays require **higher port count** at mmWave frequencies
- Signal beamforming require **new and innovative test techniques**
- Exponential volume growth drives **site count and throughput improvements** at record pace

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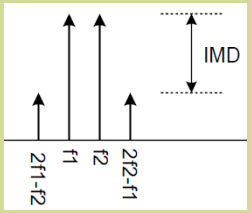
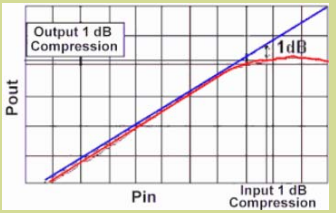
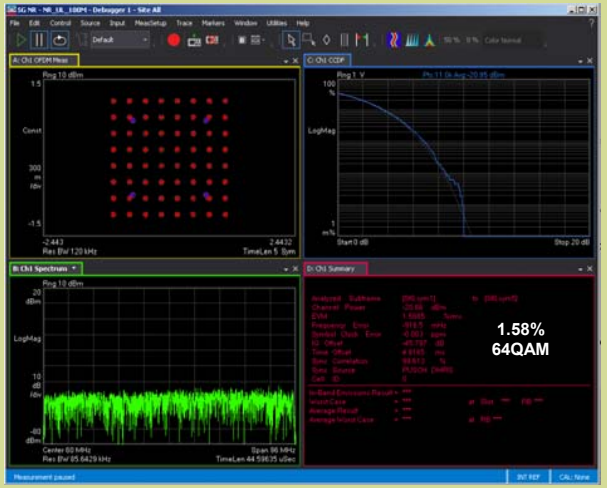
# What to test?

- **mmWave RFIC**
  - Gain
  - P1dB and IP3
  - Band pass filter(channel select) gain/flatness/out-band attenuation
  - PLL lock
  - ACLR
  - EVM
  - Phase trimming
  - Beamforming?
  - Others (DC, leakage, pattern-scan and BIST)
- **mmWave RFBB (IFIC)**
  - Gain
  - IP3
  - Low pass filter(channel select) gain/flatness/out-band attenuation
  - PLL lock
  - ACLR
  - EVM
  - IQ mismatch / IQ cal(phase and gain cal for Image rejection and carrier suppression)
  - Others (DC, leakage, pattern-scan and BIST)

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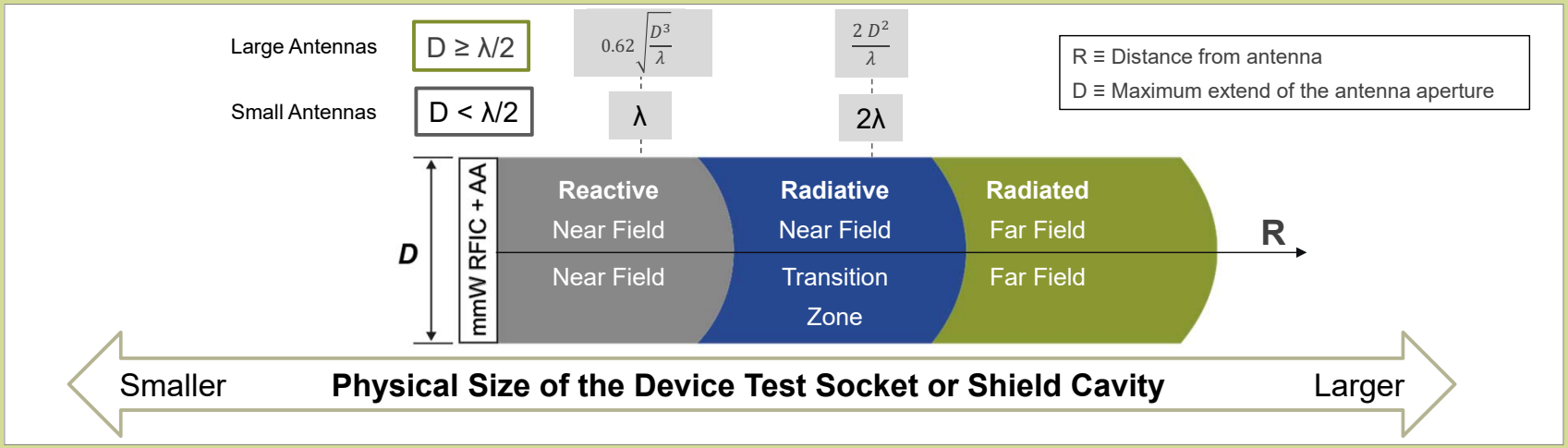
# What type of "OTA" test?




**Reactive near-field region:** It is the region where stored energy dominates. These reactive fields are generally created by strong **EM coupling** within the antenna or between antennas and very nearby electrical components. No radiative energy exists.

**Radiative near-field region (NF):** This is the region where the near fields still exist but is not dominant. Radiative near-fields start to dominate. However, the shape of **the radiation pattern may still vary appreciably with distance.**

**Far-field region (FF): the shape of the radiation pattern does not change with distance**. The spherical fields propagating outward can be considered as plane waves.

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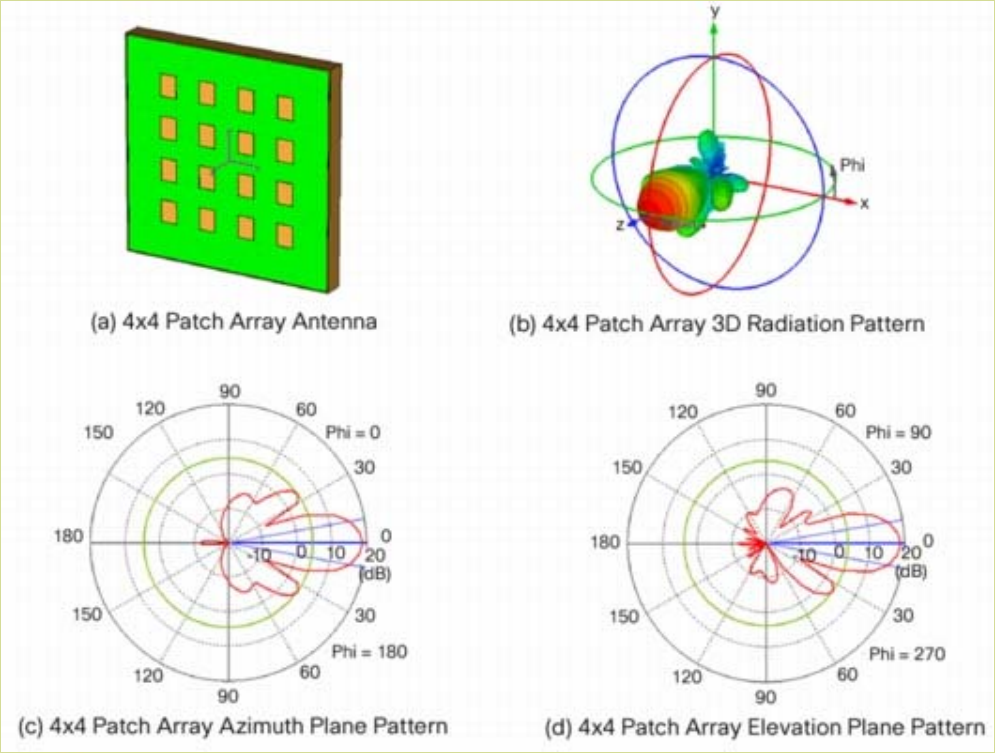
# Example of Path Antenna Array Radiation Pattern




https://e2e.ti.com/support/wireless-connectivity/bluetooth/f/538/t/839954

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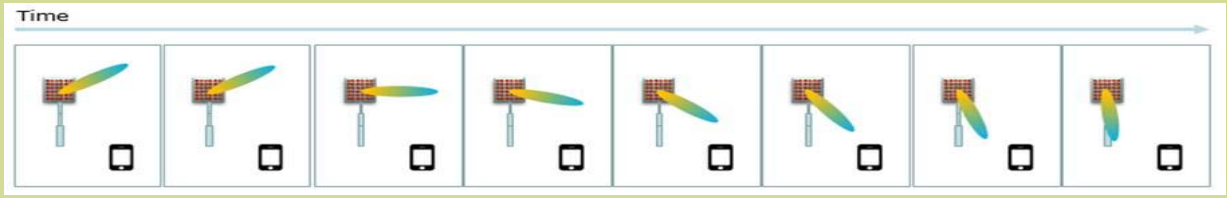
# Beamforming with Phased Antenna Arrays

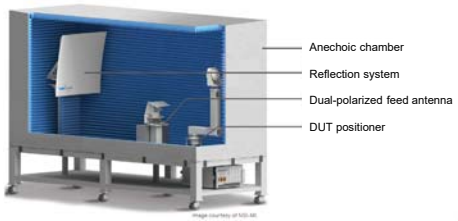
- Radiation pattern of antenna is fixed by design, thus difficult to control it or change it, unless antenna geometry is changed
- Phased antenna arrays allows for beamforming – the control of the radiation pattern on a given direction *on the fly*
  - ***Multiple antennas***
  - ***Superposition of the waves from each antenna***
  - Phased array ***can control its radiation pattern***
  - ***More antenna elements*** it has → larger its antenna aperture → ***larger the gain*** it has in the main lobe, and ***the narrower the beam***




https://www.sharetechnote.com/html/5G/5G_Phy_BeamManagement.html

# 5G mmWave Test Strategies in the Lab

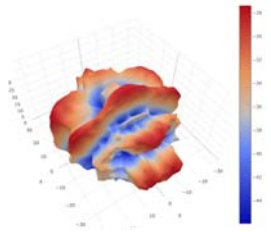
## R&D





- **Signaling and non-signaling testing required**
- VNA and VSA/VSG test equipment
- Choice of either Compact Antenna Test Range (CATR) or Direct Far Field (DFF) chamber depending on AA size.
- IF and mmWave frequencies performance test at full BW
- Different sized chambers depending on DUT size
- **Beamforming performance characterization test insertion**

## DVT

- **Non-signaling test**
- VNA and/or VSA/VSG test equipment
- Primarily a mmWave test insertion
- Different sized DFF chambers depending on AA size
- **Beamforming verification test**
- Temperature testing may be required

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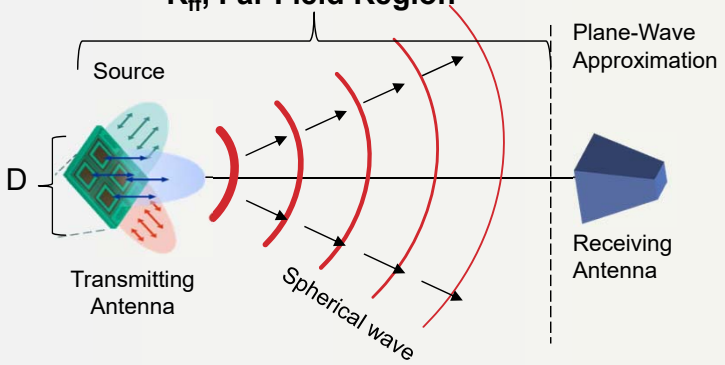
# How Big a Chamber or Shield Box for OTA Far Field Testing?

**It depends on the size of the antenna array and the application**

**$R_{ff}$, Far Field Region**




**The far-field region is at a distance R where the wave may be considered to be a plane wave**

$$R_{ff} = \frac{2D^2}{\lambda}$$

**D** = Maximum effective size of the antenna

$\lambda$ = Wavelength of the signal

**Examples for $R_{ff}$ at 28 GHz and 39 GHz**

Freq (GHz): **28** Wavelength (mm): 10.7
Assume lambda/2 antenna size

| Antenna Array | 2x2 | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 |
|---|---|---|---|---|---|---|---|
| Aperture D (mm) | 15 | 23 | 30 | 38 | 45 | 53 | 61 |
| Approx Far Field (cm) | 5 | 10 | 18 | 27 | 39 | 53 | 69 |

Freq (GHz): **39** Wavelength (mm): 7.7
Assume lambda/2 antenna size

| Antenna Array | 2x2 | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 |
|---|---|---|---|---|---|---|---|
| Aperture D (mm) | 11 | 16 | 22 | 27 | 33 | 38 | 44 |
| Approx Far Field (cm) | 4 | 7 | 13 | 20 | 28 | 38 | 50 |

For UE 2x2 Antenna, **far field** is < 6cm
(requires comparable receiving antenna D)

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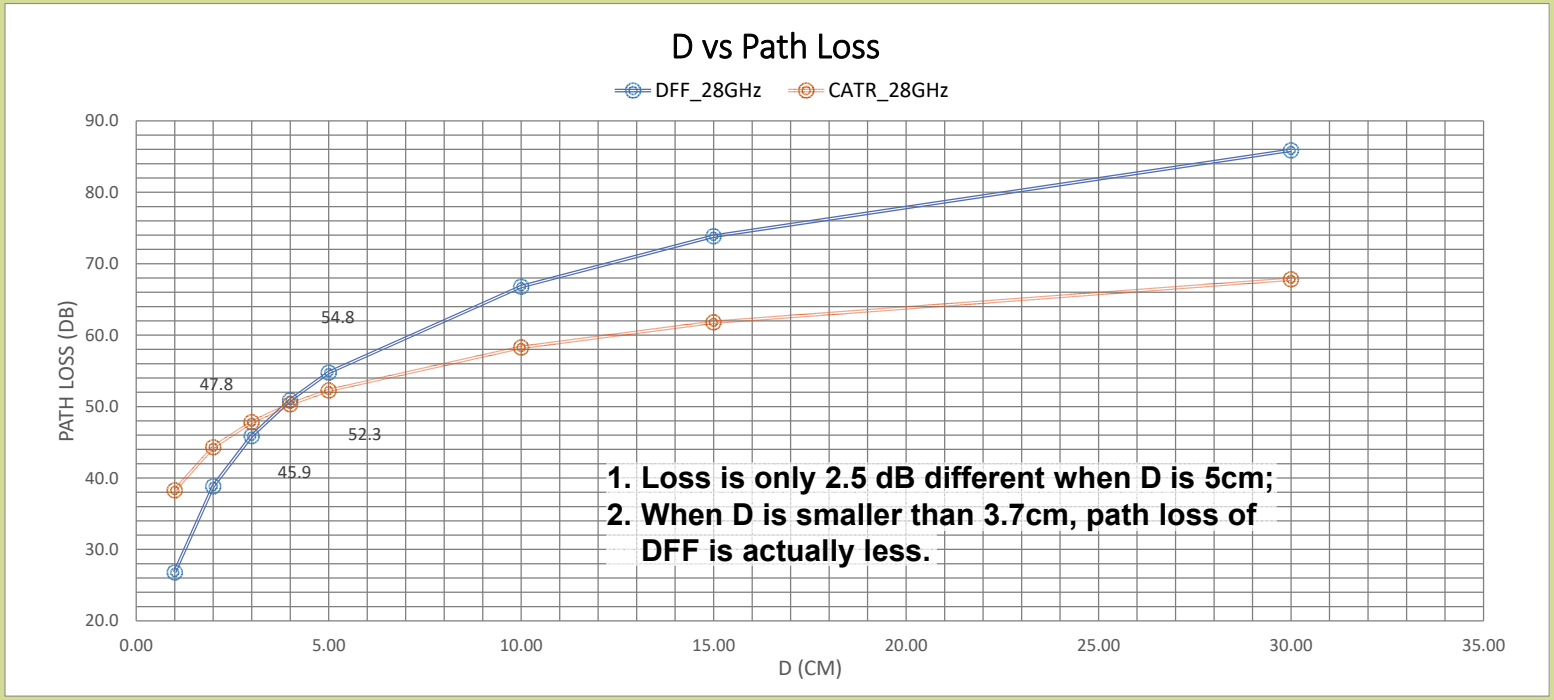
# Far-field Criteria of CATR vs DFF

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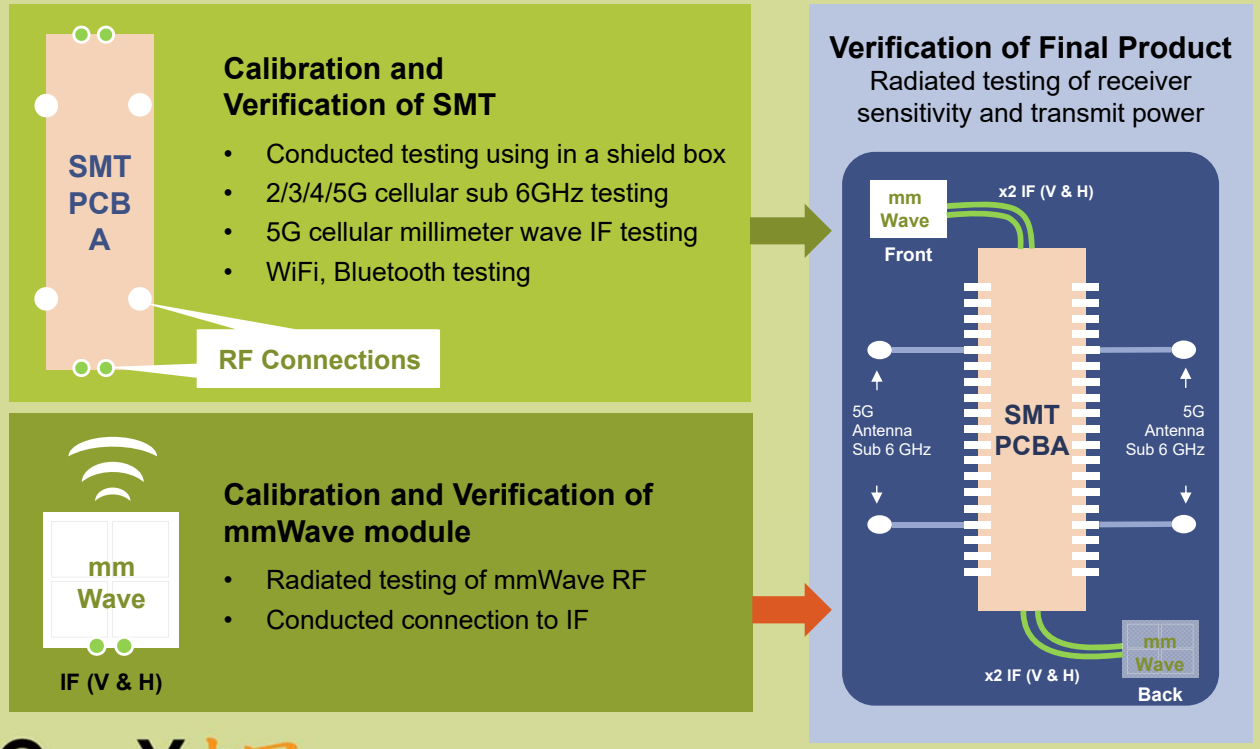
# Manufacturing Test Flow for UE Components

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## 5G mmWave Test Strategies in Mass Production

**UltraFLEX mmWave ATE**

**IQgig-5G**


| Silicon Wafer Test | Module Assembly (AiP or AoB) | Module "OTA Continuity" Test | Module Functional OTA Test | Sub-Assembly PCBA OTA Test | Final Product OTA Test |
|---|---|---|---|---|---|
| **Verify performance in order to maximize upstream test yields** | **Need 0 DPPM for mmWave Antenna Assembly** | **Need 0 DPPM for mmWave Antenna Radiation** | **Need 0 DPPM for mmWave module performance** | **Need mmWave performance test of sub-assembly antenna interaction** | **Need 0 RMA. Need mmWave performance test and calibration of final assembly antenna interaction.** |
| • **ATE Probe**<br>• CW mmWave functional test<br>• DC/Digital<br>• BIST<br>• Tri-Temp for 5G RAN | • **X-Ray Inspection** for mmWave antennas<br>• AiP vs AoB assembly yields?<br>• Multiple SKUs for different frequency bands | • **ATE Handler**<br>• OTA Socket<br>• "Continuity" test for dipole and patch antennas<br>• Limited functional tests<br>• Multiple SKUs | • **Functional Test**<br>• OTA Socket or shield box<br>• OTA NF or FF<br>• Full functional test<br>• Beamforming corner tests (FF)<br>• Multiple SKUs<br>• Tri-Temp for 5G RAN | • **System Level Test**<br>• OTA Far Field<br>• Full Functional Test<br>• Beamforming corner tests<br>• Multiple SKUs<br>• Can add value if calibration factors can be added | • **System Level Test**<br>• OTA Far Field<br>• Full Functional Test<br>• Full CC BW EVM Test<br>• Full CA Test Possible<br>• Beamforming calibration<br>• Multiple SKUs<br>• Tri-Temp for 5G RAN |

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= Must = Likely = Optional

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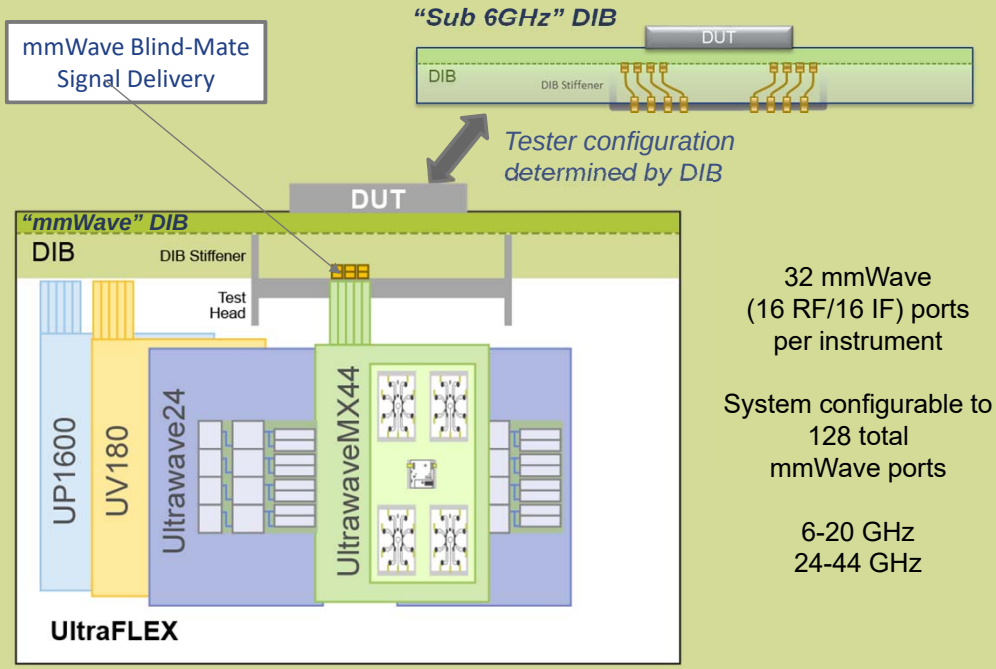
# Need ATE with a Simple Upgrade from Sub 6GHz to mmWave: *UltraWaveMX44*

- Zero change to existing DIB load board standard
- No system reconfiguration required to switch between sub-6GHz and mmWave applications
- Performance specified at blind-mate with fully integrated calibrations
- No change to docking or Z-height




32 mmWave (16 RF/16 IF) ports per instrument

System configurable to 128 total mmWave ports

6-20 GHz
24-44 GHz

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https://www.teradyne.com/products/test-solutions/semiconductor-test/ultraflex-mmwave-instruments

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# Summary

- The 5G Era has arrived
  - 5G NR standards are ready; new spectrum is available; 5G devices are ready for volume ramp; 5G infrastructure roll out is happening.
- 5G devices have 2-3 times more ICs than 3G/4G devices
  - 5G complexity adds more risk for field failures
  - If 5G Fails, your Brand Fails
- 5G is changing the strategy for device testing
  - Increased frequency range into mmWave requires **OTA test innovation**
  - Phase array high antenna density requires **higher port-count** mass production ATE
  - Need an **easy system upgrade from sub-6GHz to mmWave** test coverage
  - Need **low cost of test, fast time to market, and high-performance** testing instrumentation for mass production
  - Teradyne millimeter wave test solutions are at the forefront of the 5G Era.

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## What Does it Take to Build a 5G Network?

1. Define the Standard ✓
2. Assign the Spectrum ✓
3. Develop Devices ✓
4. Roll out Infrastructure ✓

and **Test, Test, Test!**

✓ **UltraFLEX mmWave ATE**


https://www.teradyne.com/products/mmwave/

✓ **IQgig-5G mmWave**


https://www.litepoint.com/products/iqgig-5g/

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TTS Group is dedicated to bring the best possible testing solutions to our customers and to help solve some of the most challenging issues in test and tooling today.

**Total headcount of 400 specialists**

**Total production area of 400,000 sqft. for Probe Pin and Socket operations**

**Total investment of USD 75 Million**

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