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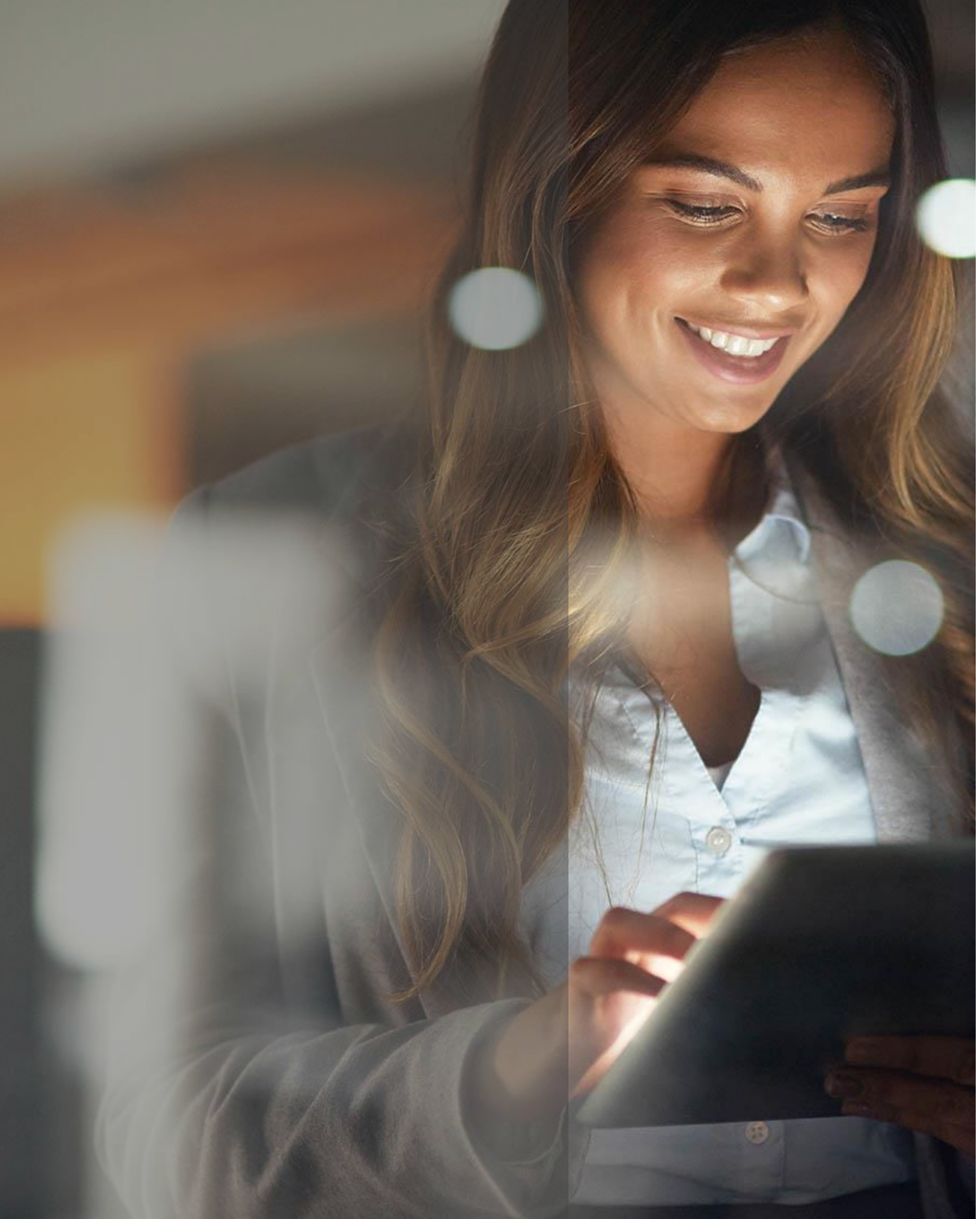
A Teradyne Company

Solving the Wi-Fi 6E Performance Challenges in DVT and Manufacturing



Agenda

- Wi-Fi Evolution: Wi-Fi 6, 6E and 7:
  - Worldwide spectrum adoption
  - Market updates
  - Wi-Fi 6E chipsets roundup
  - Wi-Fi 7
- Wi-Fi 6E Channels and Operating Rules
  - IEEE channels allocation
  - Classes of power
- Wi-Fi 6E Top Performance Challenges
  - Identifying performance bottlenecks
  - Increased frequency range
  - Coexistence
  - High data rates
  - Wider Channels
  - Multi-User OFDMA
- Wi-Fi 6E Test Strategy

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Wi-Fi Evolution: Wi-Fi 6, 6E and 7

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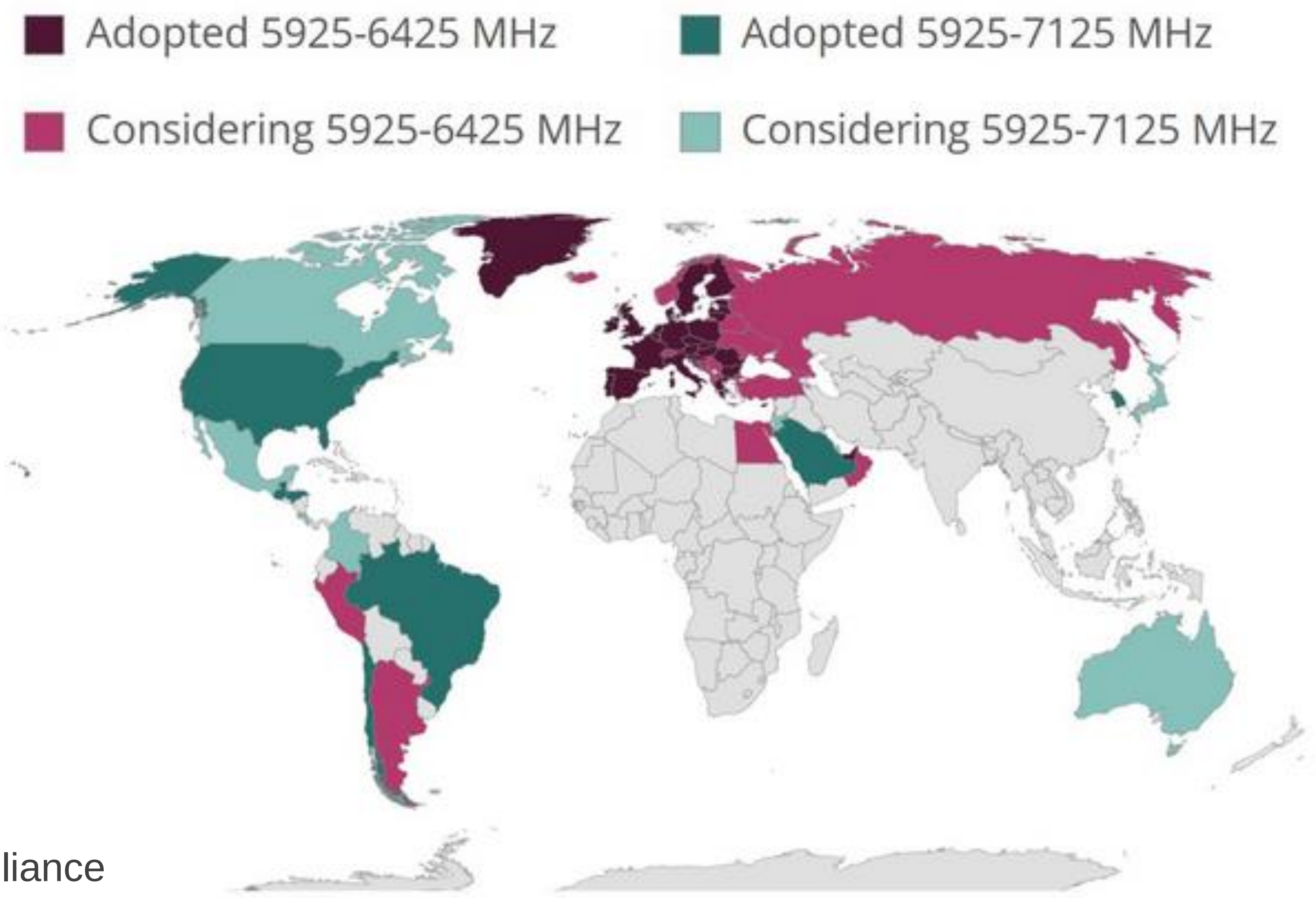
6 GHz Band Regulatory Approval



Source: Wi-Fi Alliance

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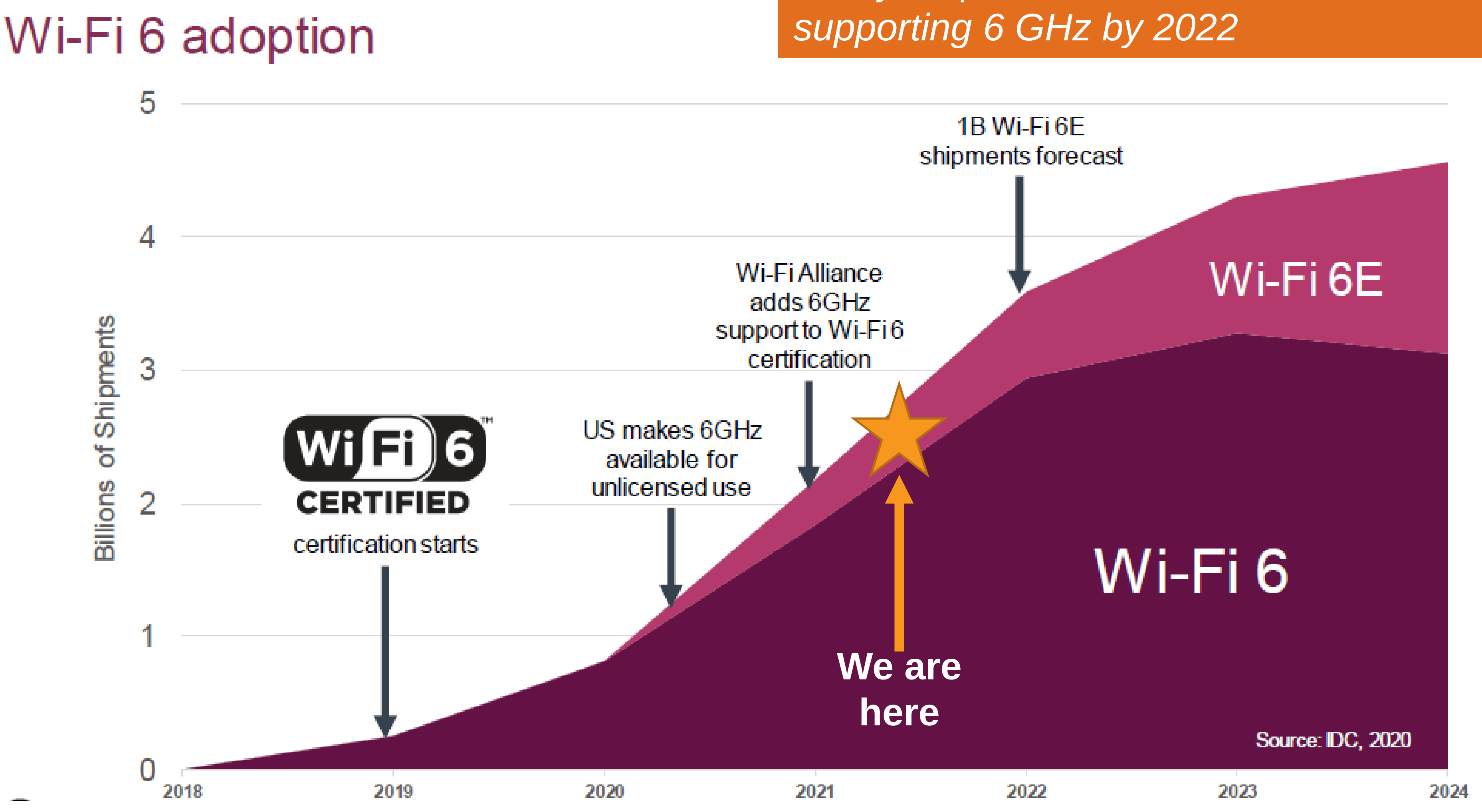
Wi-Fi 6E Market Update

nearly 20 percent of all Wi-Fi 6 device shipments supporting 6 GHz by 2022



Source: Wi-Fi Alliance

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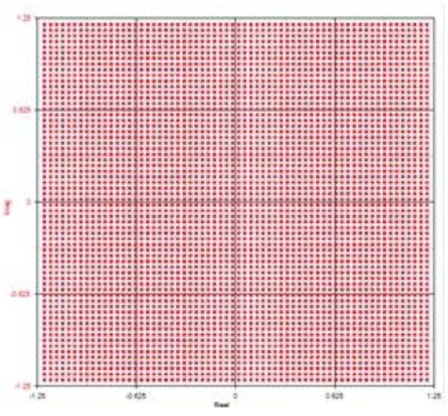
802.11be (Wi-Fi 7) EHT Extreme High Throughput

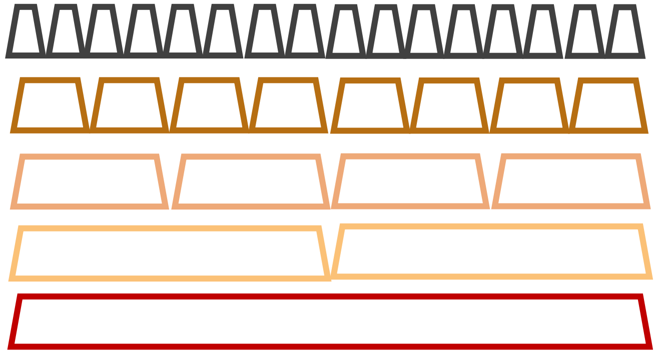
Target Performance for AR and VR

- Low Latency: < 5 ms (full immersion VR)
- High Throughput: 30 Gbps

- Features:

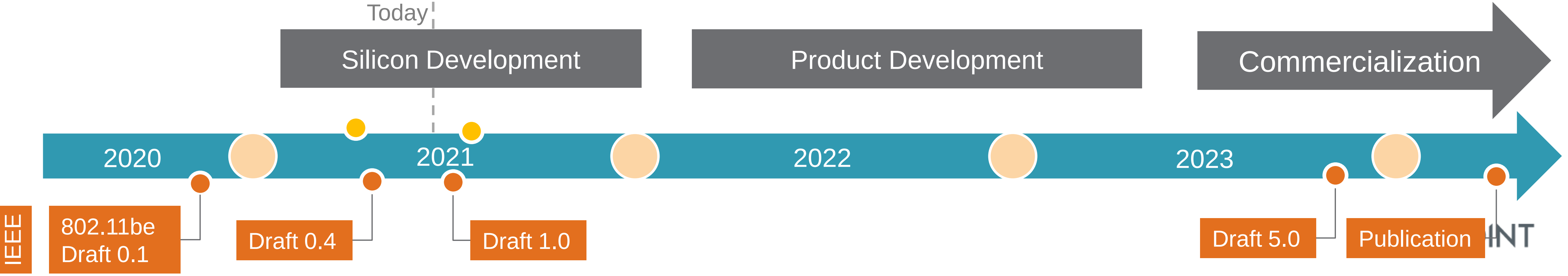


4096 QAM

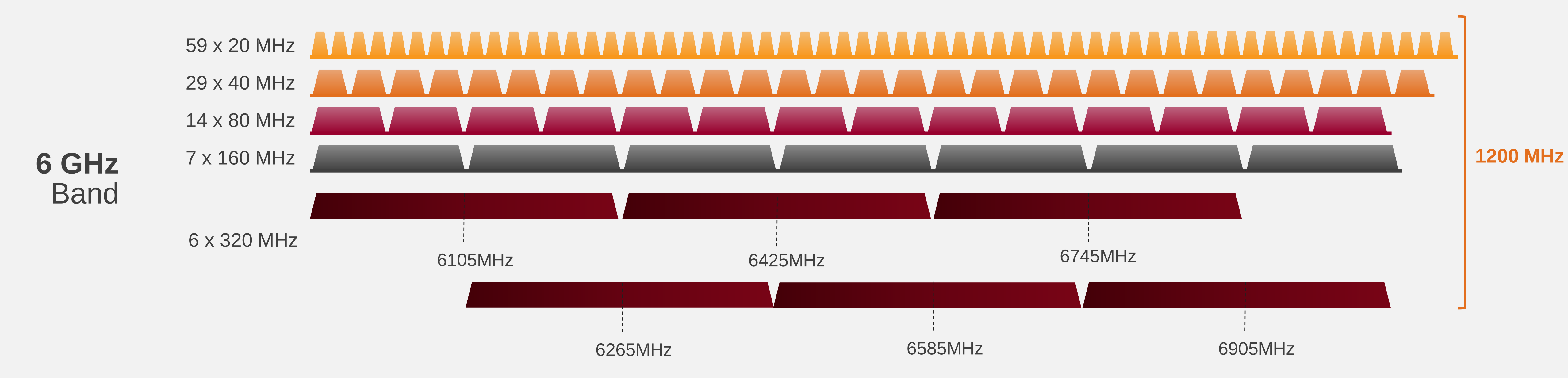


320 MHz Channel

Wi-Fi 7 Timeline



320 MHz channels in the 6 GHz band



3 non-overlapping 320 MHz channels
6 overlapping 320 MHz channels

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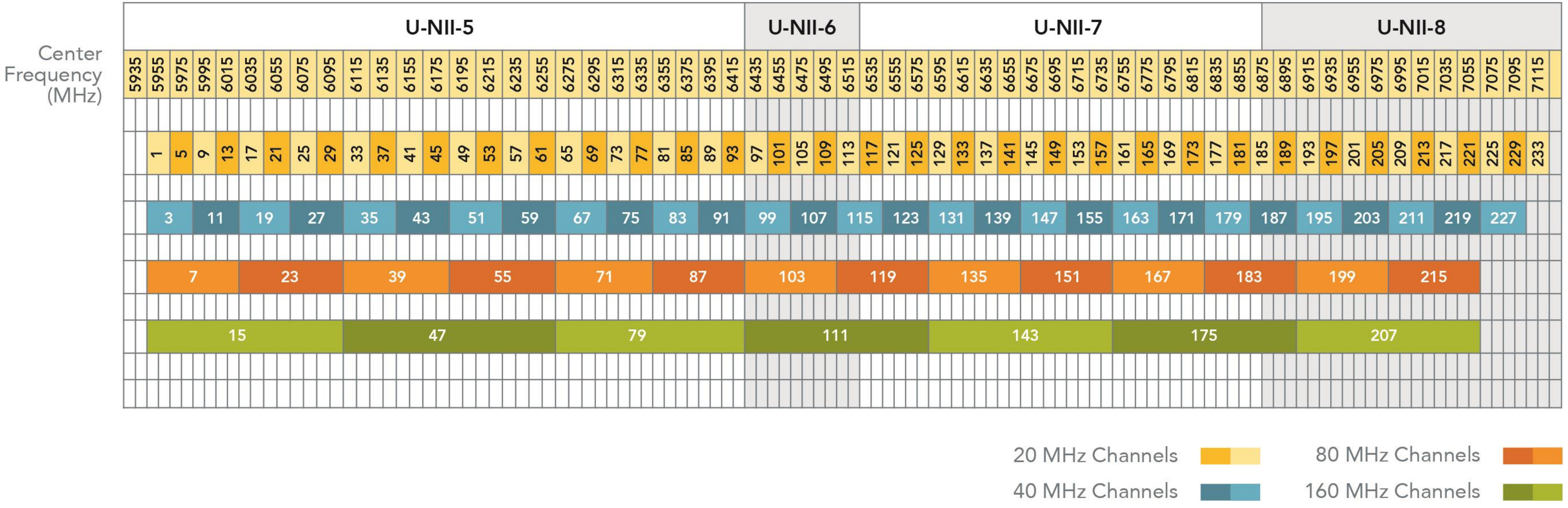
Key Changes in Wi-Fi 7

	802.11ac Wi-Fi 5	802.11ax Wi-Fi 6	802.11be Wi-Fi 7
Operating Bands	5GHz	2.4 & 5GHz 6GHz	2.4 & 5GHz 6GHz
Technology	OFDM	UL/DL OFDMA	UL/DL OFDMA
MU-MIMO	DL MU-MIMO	DL / UL MU-MIMO	DL / UL MU-MIMO
Modulation	256QAM	1024QAM	4096QAM
User Streams	Up to 8 user streams		Up to 16 user streams
Bandwidth	20, 40, 80, 80+80 and 160MHz		20, 40, 80, 80+80, 160, 160+160, 320 MHz
Multi-Link Operation (MLO)			Yes
Enhanced OFDMA			Preamble puncturing, Multi-RU

Wi-Fi 6E Bands, Channels and Operation

Wi-Fi 6E Channels



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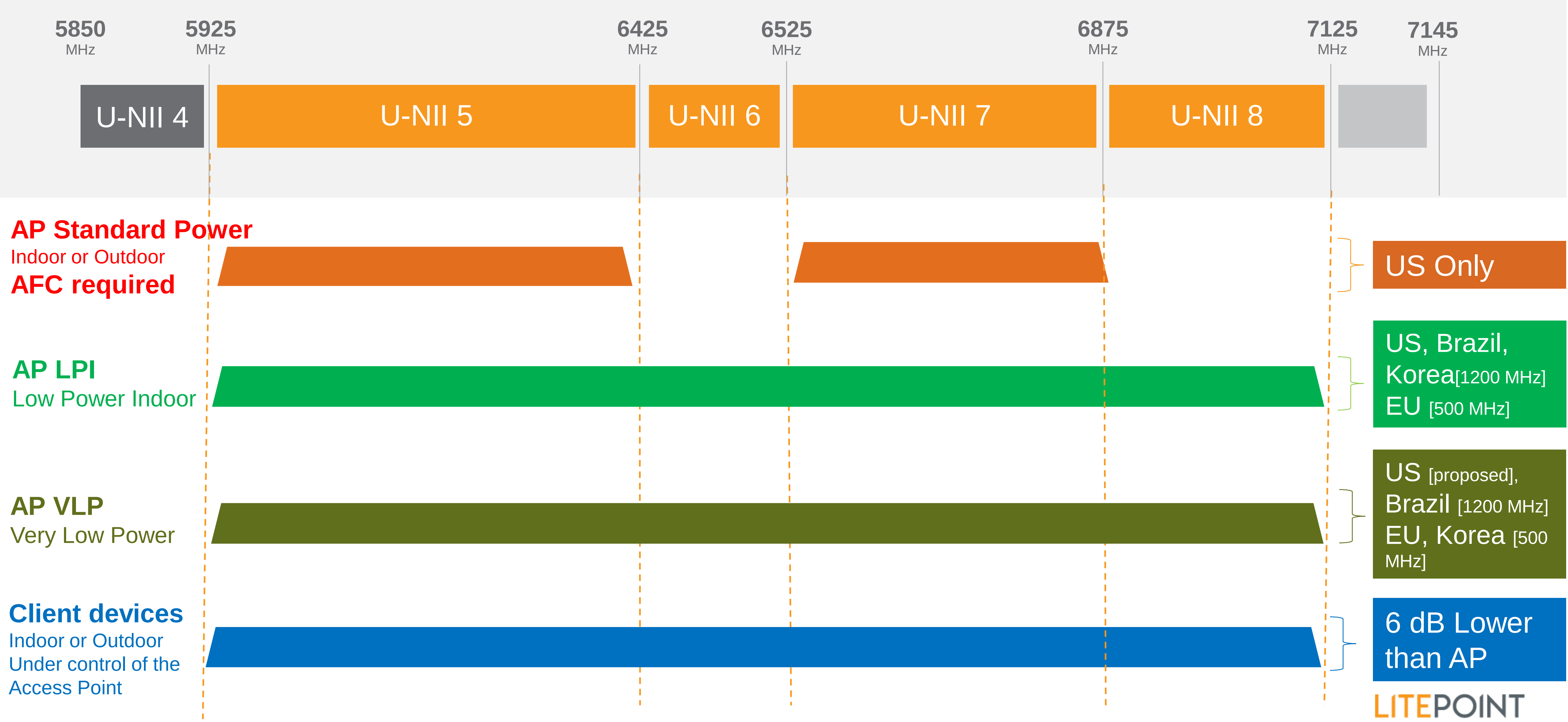
6 GHz band and Classes of Power



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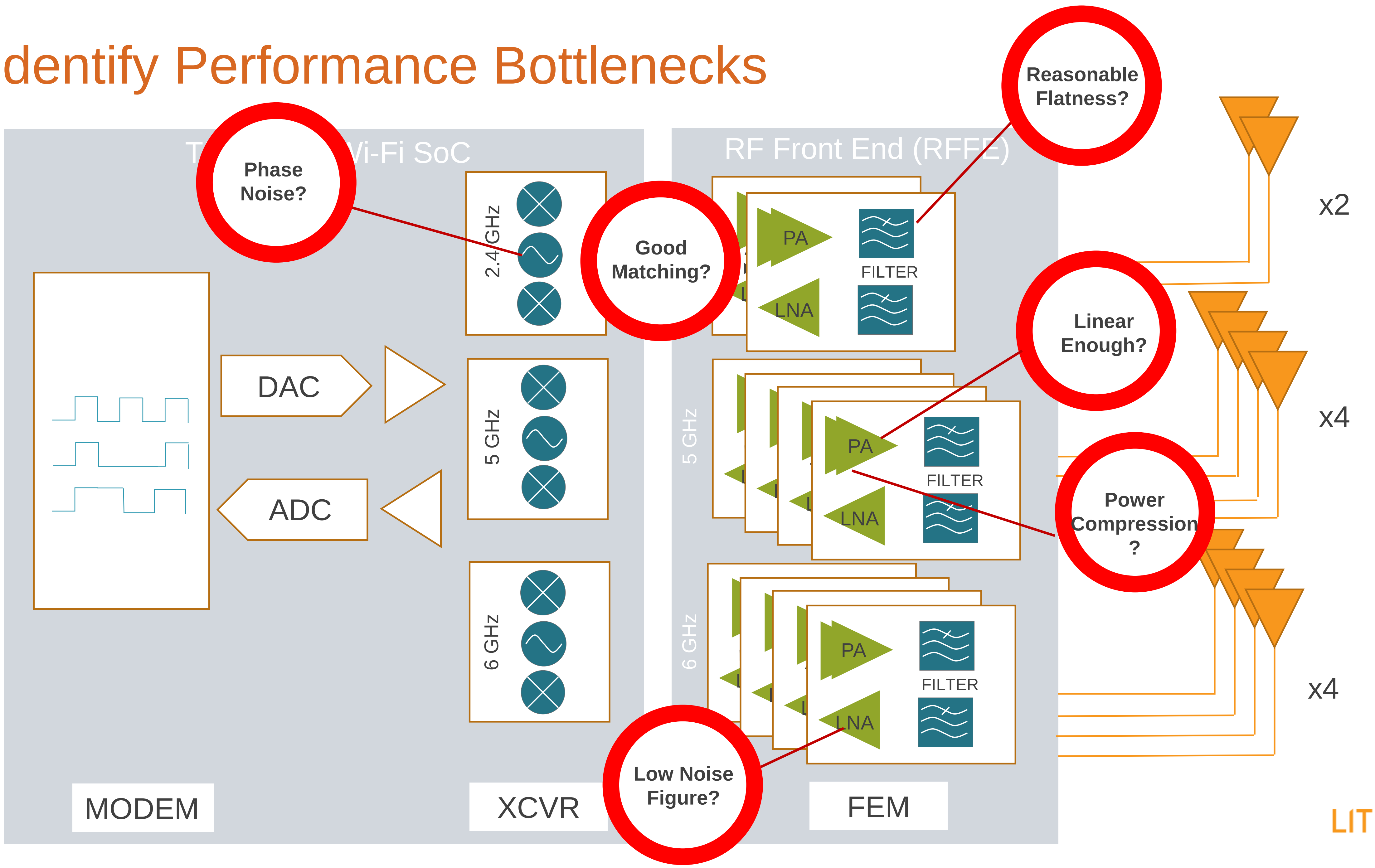
AP Power Classes Summary

	MAX AP EIRP	MAX AP PSD
Standard Power	36 dBm (US)	23 dBm/MHz (US)
Low Power Indoor	30 dBm (US) 23 dBm (EU)	5 dBm/MHz (US) 10 dBm/MHz (EU)
Very Low Power	14 dBm (US) 14 dBm (EU)	-8 dBm/MHz (US) 1 dBm/MHz (EU)

- Standard Power (US only): Operation not allowed on Mobile bands (U-NII 6 & 8). Operation requires Automated Frequency Coordination (AFC).
- *The AFC system provides a list of frequencies where the AP can operate safely without interfering with incumbent fixed microwave receivers*
- Low Power Indoor : Operation allowed Indoors only. No weather resistant enclosure, cannot operate solely on battery power and integrated antennas
- Very Low Power: Operation allowed indoor/outdoor but low power restriction

Wi-Fi 6E Performance Challenges

Identify Performance Bottlenecks



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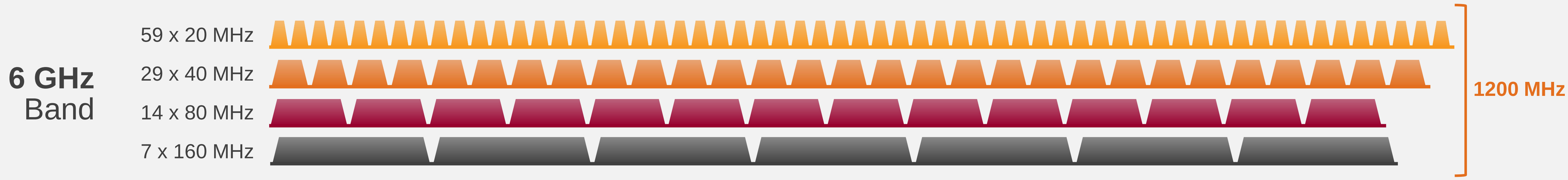
5 Wi-Fi 6E Key Performance Challenges

- 1200 MHz of Additional Frequency Coverage
- Power Spectrum and Coexistence
- High Order Modulation
  - 1024 QAM
  - 4096 QAM
- 160 MHz Channels
- Multi-User Operation
  - OFDMA

Challenge #1: Increased Frequency Range Coverage

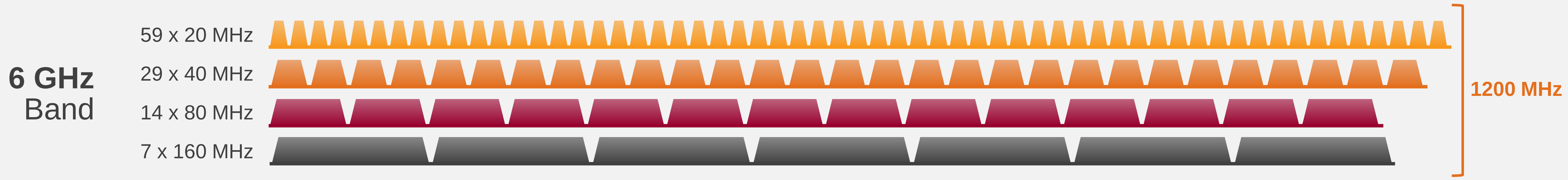
➢ **1200 MHz of additional spectrum (twice the amount of spectrum of 2.4 and 5 GHz bands combined)**



- RFFE must cover wide bandwidth with high linearity
- PA must be efficient at high frequencies
- Gain roll off faster at high frequencies
- PA linearity determines RF range and signal coverage

Solution:

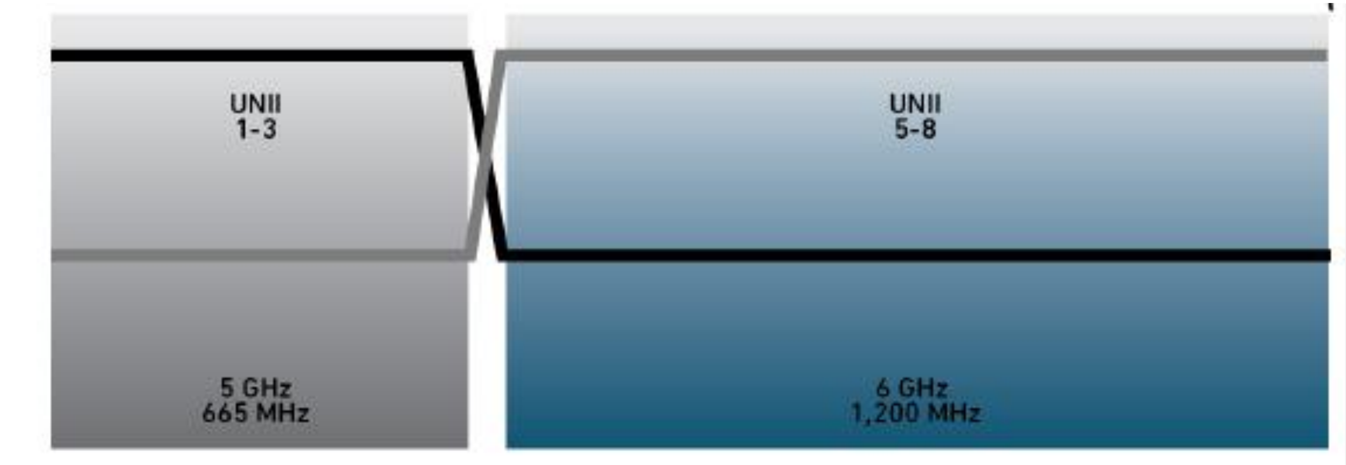
➢ **Increase Test Coverage to include 6 GHz band**



- Manufacturing Test Coverage must include channels in the 6 GHz band.
- Verify per-DUT performance in low, mid and high 6 GHz band at maximum power to detect non-linearities

Challenge #2: Power Spectrum and Coexistence

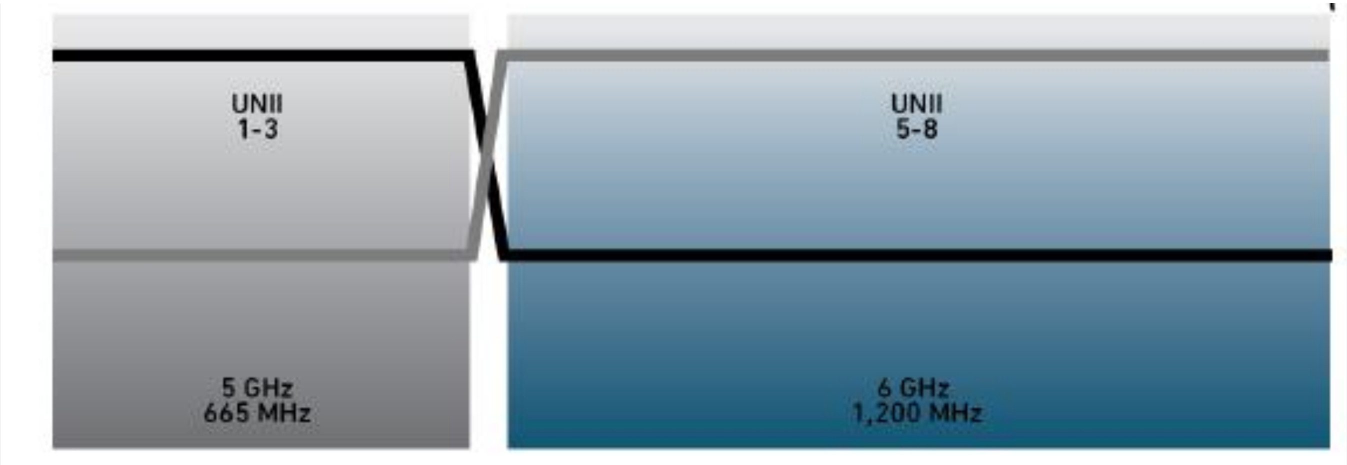
- **Only 75 MHz guard band between 5 GHz and 6 GHz band and only 25 MHz guard band between UNII-4 (Vehicle DSRC) and UNII-5**



- Challenging filtering for OOB emissions
- Compromises power level on first 6 GHz channels, especially first 160 MHz channel (highest power)

Solution

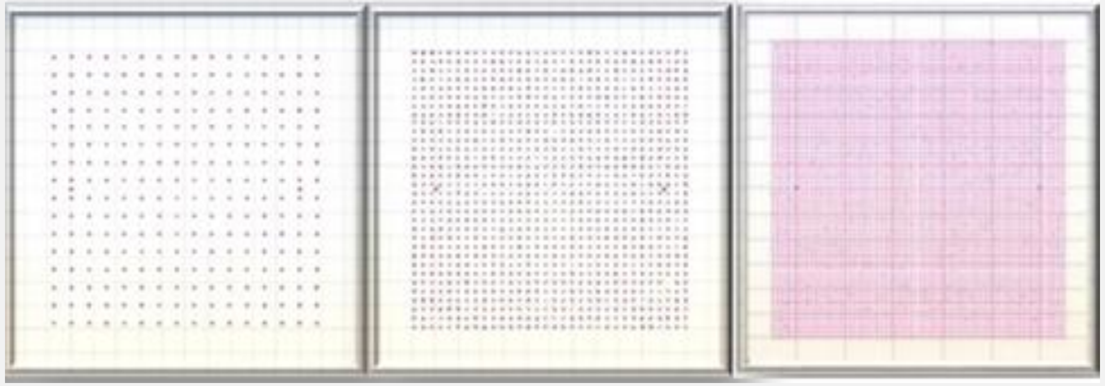
➢ **Calibrate and verify TX Power**



- Per-DUT Transmitter calibration ensures maximizing output power while remaining compliant to emissions
- Spectral Mask and Power verification for channels in the low, mid and high 6 GHz band, includes verification for 20, 40, 80 and 160 MHz

Challenge #3: 1024 QAM, 4096 QAM

- **Higher order QAM give the highest throughput but increases performance requirements**



EVM DUT Spec
(system level)

256 QAM	**1024 QAM**	**4096 QAM**
-32 dB	**-35 dB**	**-38 dB**

- High QAM rate requires low EVM floor to ensure Transmitter accuracy: IEEE: -35 dB for MCS 10, 11 and -38 dB for MCS 12, 13
- EVM Degradation comes from phase noise and PA non-linear distortions due to gain in compression region
- High QAM rate increases receiver sensitivity requirements

Solution

➢ Measure Transmitter Modulation Accuracy

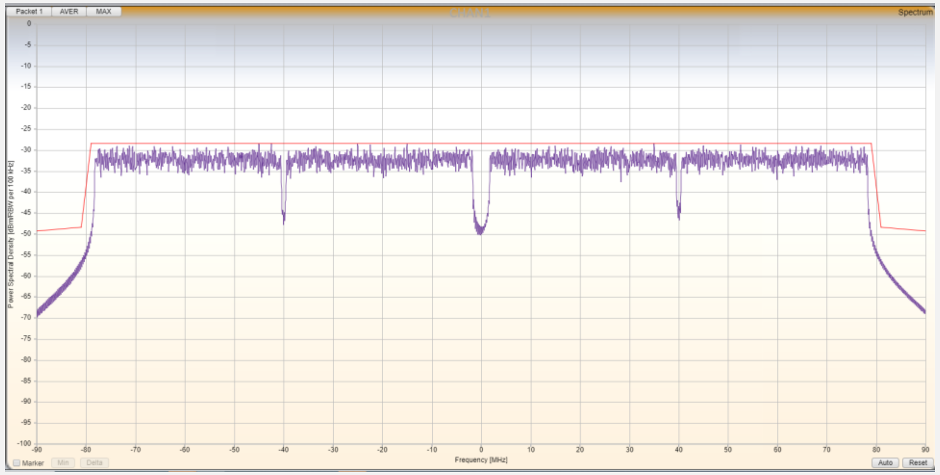
EVM DUT Spec (system level)

256 QAM	1024 QAM	4096 QAM
-32 dB	-35 dB	-38 dB

- EVM Measurements indicator of the combined effects of all the possible defects on the transmitter chain
- EVM floor of test equipment requires 10 dB better than DUT to ensure low error margin and ensure accuracy of measurements

Challenge #4: 160 MHz Wide Channels

➢ **Wi-Fi 6E Chips support 160 MHz Channels, more 160 MHz channels will be deployed in 6 GHz band**



- 802.11ax narrows subcarrier spacing (4 times narrower spacing at 78.125 kHz) – 1992 sub-carries in 160 MHz channel
- Distortions occur when the carriers at different frequencies are attenuated or amplified by different factors
- Larger range of frequencies increase likelihood of distortions

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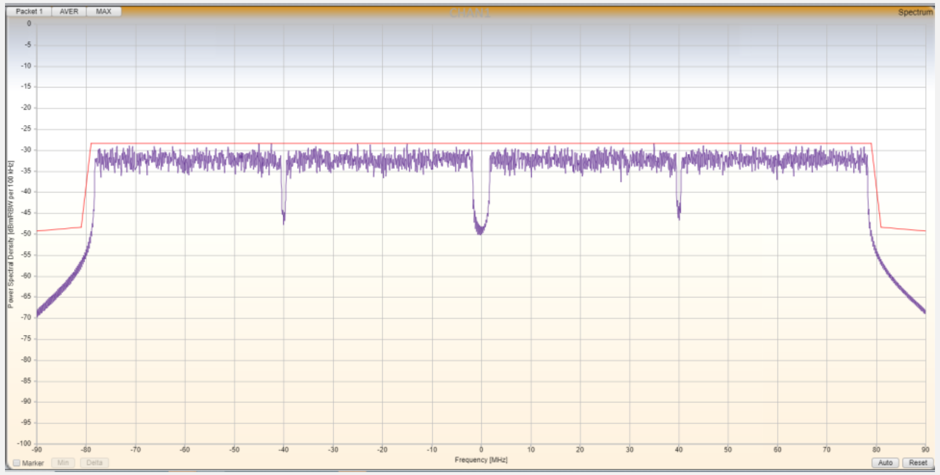
Solution

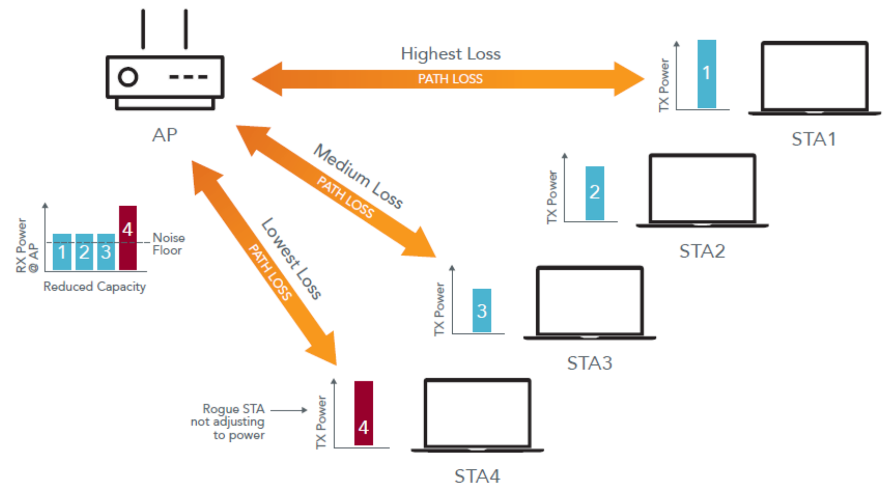
➢ **Measure Transmitter Accuracy for 160 MHz channels**



- Spectral Flatness ensures that power is spread out evenly over the channel

Challenge #5: Power Level and RSSI Accuracy

➢ **802.11ax OFDMA Multi-User requires STA to precisely control TX Power**



Parameter	Minimum Requirement		Comments
	Class A	Class B	
Absolute transmit power accuracy	±3 dB	±9 dB	Accuracy of achieving a specified transmit power.
RSSI measurement accuracy	±3 dB	±5 dB	The difference between the RSSI and the received power. Requirements are valid from minimum Rx to maximum Rx input power.
Relative transmit power accuracy	N/A	±3 dB	Accuracy of achieving a change in transmit power for consecutive HE TB PPDU. The relative transmit power accuracy is applicable only to Class B devices.

- For UL MU-OFDMA 802.11ax standard requires STA to precisely measure RSSI to evaluate path loss
- STA are required to precisely adjust they TX power to participate in UL MU-OFDMA transmission
- +/- 3 dB RSSI accuracy and +/- 3 dB TX power accuracy for Class A

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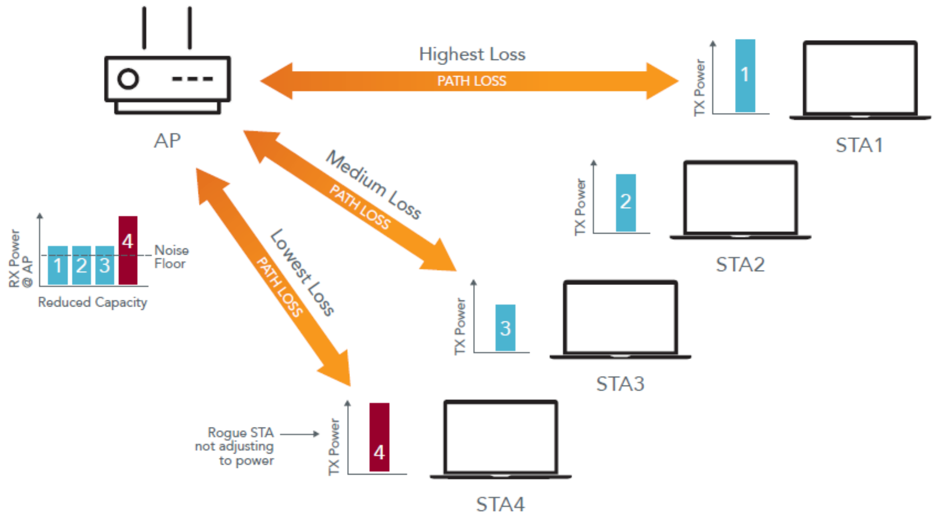
Solution

➢ RSSI and TX Power Calibration



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- Per-DUT RSSI and Transmitter calibration ensures compliance to 802.11ax UL MU-OFDMA Transmission
- Both RSSI cal. and Power cal. are needed to achieve IEEE 802.11ax compliance

Wi-Fi 6E Test Strategy

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Choosing an Optimized Test Plan

Test items can be greatly reduced maintaining verification *quality* and limiting *cost*:

- ✓ Choosing the right combination of channels, data rates, bandwidths and bands based on WLAN system functionalities.
- ✓ Choose a test plan to uncover specific failure mechanisms

1200 MHz of Additional Frequency Coverage	Power Spectrum and Coexistence	High Order Modulation 1024 QAM 4096 QAM	160 MHz Channels	Multi-User Operation OFDMA

Transmitter Verification:

TX Power, Error Vector Magnitude & Spectrum Mask

Priority to be tested:

- **Highest data rates**
  - They have the tightest limits
  - They are more sensitive to phase noise, compression, etc…
- **Lowest data rate**
  - Some chipsets utilize low data rates to increase the transmit power to further improve the range. High power can cause compression, degrading EVM and spectral mask (SEM)
- **Highest channel per band -**
  - Phase noise increases with frequency
  - Worst filter roll-off (insertion loss)
- **Lowest channel**
  - To validate filter ripple and noise figure effects
- **Mixed bandwidths**
  - Wider and narrow bandwidths have different SNR effects
- **Maximum power level**
  - Compression in the transmitter degrades the EVM and spectral mask (SEM)

⚠ 1024-QAM and 4096-QAM

⚠ Test the highest 6GHz band channels

⚠ Test 20, 40, 80 and 160 MHz channels

Receiver Verification:
RX Sensitivity and Max Input Level

1024-QAM and 4096-QAM ⚠

Test the highest 6GHz band channels ⚠

Test 20, 40, 80 and 160 MHz channels ⚠

Priority to be tested:

- **Highest data rate**
  Because it is more sensitive to impairments
- **Lowest data rate**
  To detect ACK packets and ACK power
  Because longer packets are more sensitive to noise spikes
- **Highest channel**
  Because phase noise increases with frequency
- **Lowest channel**
  To validate filter ripple and noise figure effects
- **Mixed bandwidth**
  Wider and narrow bandwidths have different SNR effects

Wireless Test in the Manufacturing Cycle

	Design Validation Testing	Manufacturing PCB Test	End of Line
Objectives	**High yielding design that meets requirements**	**Optimize RF Performance Screening manufacturing defects**	**Meet regulations, meet user experience expectations**
Tests	**TX Calibration, RSSI Calibration Power Frequency Spectrum Modulation quality (EVM) Rx sensitivity (PER) MIMO Testing OFDMA (timing, power, CFO) Sweeps over wide temperature range, frequencies and power levels**	**TX Calibration RSSI Calibration Power Frequency Spectrum Modulation quality (EVM) Rx sensitivity (PER)**	**Tx Power RX Sensitivity**
Outcome	**Identify Design issues with PCBA layout, Component selection, Firmware**	**Calibration reduces variation and improves yield. Identify assembly defects(wrong part values, out of tolerance, cracked caps, etc.)**	**Identify assembly defects and identifies interactions problems with other components (antenna connection, noisy subsystems, bad grounding.)**

Wi-Fi 6E Test Coverage: DVT and Manufacturing

Test Category 2.4 GHz, 5 GHz, 6 GHz	Test Items	DVT	Manufacturing
Calibration	TX Cal	**Required**	**Required**
	RSSI Cal	**Required**	**Strongly Recommended**
TX Verification	TX EVM	**Required**	**Strongly Recommended**
	TX Spectral Flatness	**Required**	**Recommended**
	Transmit center frequency leakage (LO leakage)	**Required**	**Recommended**
	Transmit center frequency tolerance	**Required**	**Recommended**
	Symbol Clock frequency tolerance	**Required**	**Recommended**
	Transmit spectrum mask	**Required**	**Recommended**
	Transmit Power + Regulatory Limit	**Required**	**Strongly Recommended**
Trigger Based Test (UL OFDMA Performance)	Power Control Test	**Required**	**Recommended**
	EVM Mask	**Required**	**Recommended**
	Residual CFO Test	**Required**	**Recommended**
	Timing Synchronization	**Required**	**Recommended**
Receiver Verification	RX PER (Sensitivity)	**Required**	**Strongly Recommended**
	Sensitivity with MU DL signal	**Required**	**Recommended**

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IQxel-MW 7G

The *IQxel-MW 7G* is LitePoint’s test solution for advanced Wi-Fi 6 and 6E testing on 2.4GHz, 5 GHz and 6 GHz frequency bands

- Continuous frequency range from 400 MHz to 7300 MHz
- 80+80, 160MHz and dual-band concurrent on a single port
- Exceeds stringent 802.11ax EVM requirements over entire frequency range
- Packet detection and timing capabilities for advanced Wi-Fi 6 testing
- True MIMO testing support
- Support for all Wi-Fi standards: WiFi 6/6E (11ax), WiFi 5 (11ac) and 802.11 a/b/g/n/ah/af
- Support for major connectivity technologies: BT, Zigbee, Z-Wave, Sigfox DECT and LTE
- Easy test program migration from IQxel-M and IQxel-MW

Simplify DVT to Production Deployment

Common Platform for easiest correlation from DVT to high volume manufacturing

Design Validation Testing

Correlation

- **Same HW**
- **Same SW**

Common Platform

Manufacturing

- ***Optimized Performance – DVT to MFG***
- ***Single DUT to Multi-DUT – Configurable, Same HW***

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-END-

THANK YOU