5G Technology Overview and Measurement Solution

You Gwang-Yeol

KEYSIGHT TECHNOLOGIES

Agenda

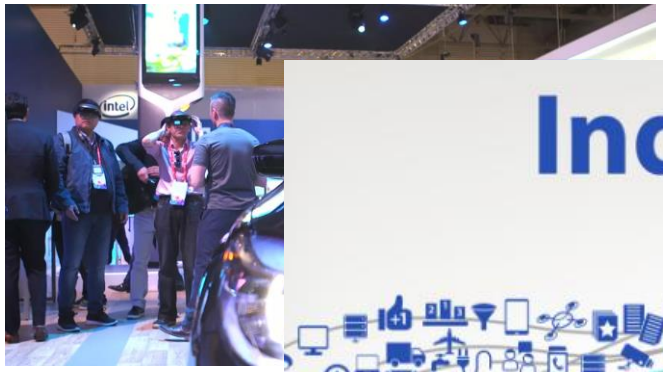
- 5G Vision & Enabling Technologies
- 5G Timeline & Standard update
- mmWave System considerations
- 5G Solution in Keysight
  - ✓ HARDWARE+SOFTWARE+PEOPLE=5G INSIGHTS
  - ✓ Measurement examples

https://www.youtube.com/watch?v=8I1xKEX8zSc

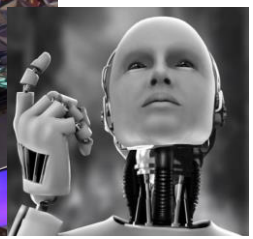
MWC 2017 Trends

KEYWORD : 5G, IoT, AI, Connected Car, Robot, MR

Autonomous Driving



Artificial Intelligence



Robot

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5G Drivers and Vision

Massive Growth in Mobile Data Demand

Massive Growth in No. of Connected Devices

Exploding Diversity of Wireless Applications

Dramatic Change in User Expectations of Network

For the User*

Amazingly fast

Great service in a crowd

Best experience follows you

Super real-time and reliable communications

Ubiquitous things communicating

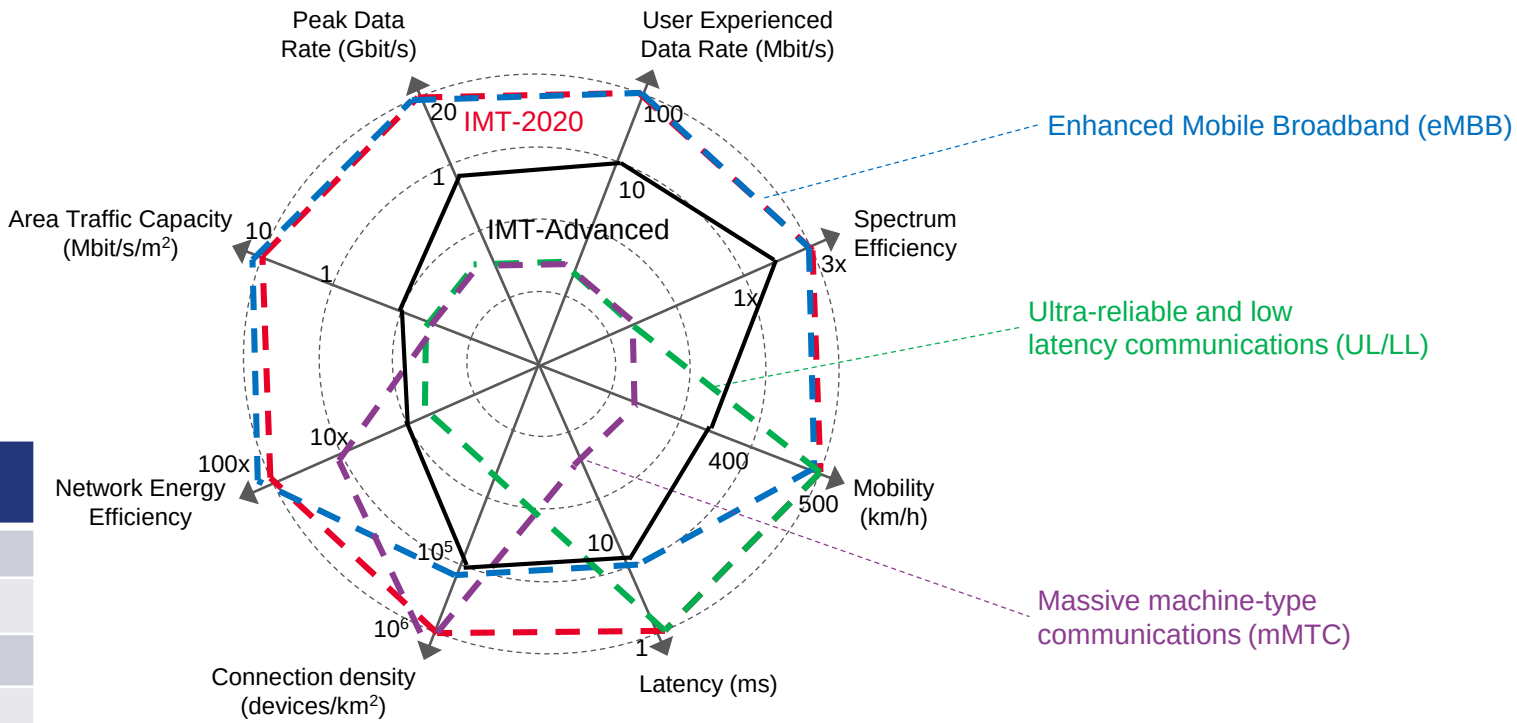
*Courtesy of METIS

- 100x Data Rates
- 1000x Capacity
- 100x Densification
- 1ms Latency
- Reliability 99.999%
- 100x Energy Efficiency

All founded on a solid business model

5G Key Performance Indicator from ITU-R IMT-2020 vision

KPIs and Proposed 5G use cases



Additional KPI for IMT-2020
Reliability
Average spectral efficiency
Mobility interruption time
Bandwidth
5th percentile user spectral efficiency

Proposed 5G Use Cases

eMBB

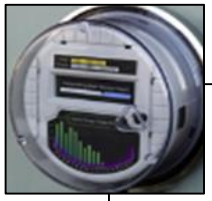
Enhanced Mobile Broadband (eMBB)

- 10-20 Gbps peak
- 100 Mbps whenever needed
- 10000x more traffic
- Support for high mobility (500 km/h)
- Network energy saving by 100 times

Virtual Reality

Augmented reality

mMTC



Massive Machine Communication (mMTC)

- High density of devices ($2x10^5$ - $10^6/km^2$)
- Long range
- Low data rate (1 - 100 kbps)
- M2M ultra low cost
- 10 years battery
- Asynchronous access

UR/LL

Ultra reliability and low latency (UR/LL)

- Ultra responsive
  - <1 ms air interface latency
  - 5 ms E2E latency
- Ultra reliable and available (99.9999%)
- Low to medium data rates (50 kbps - 10 Mbps)
- High speed mobility

Driverless car

Remote surgery

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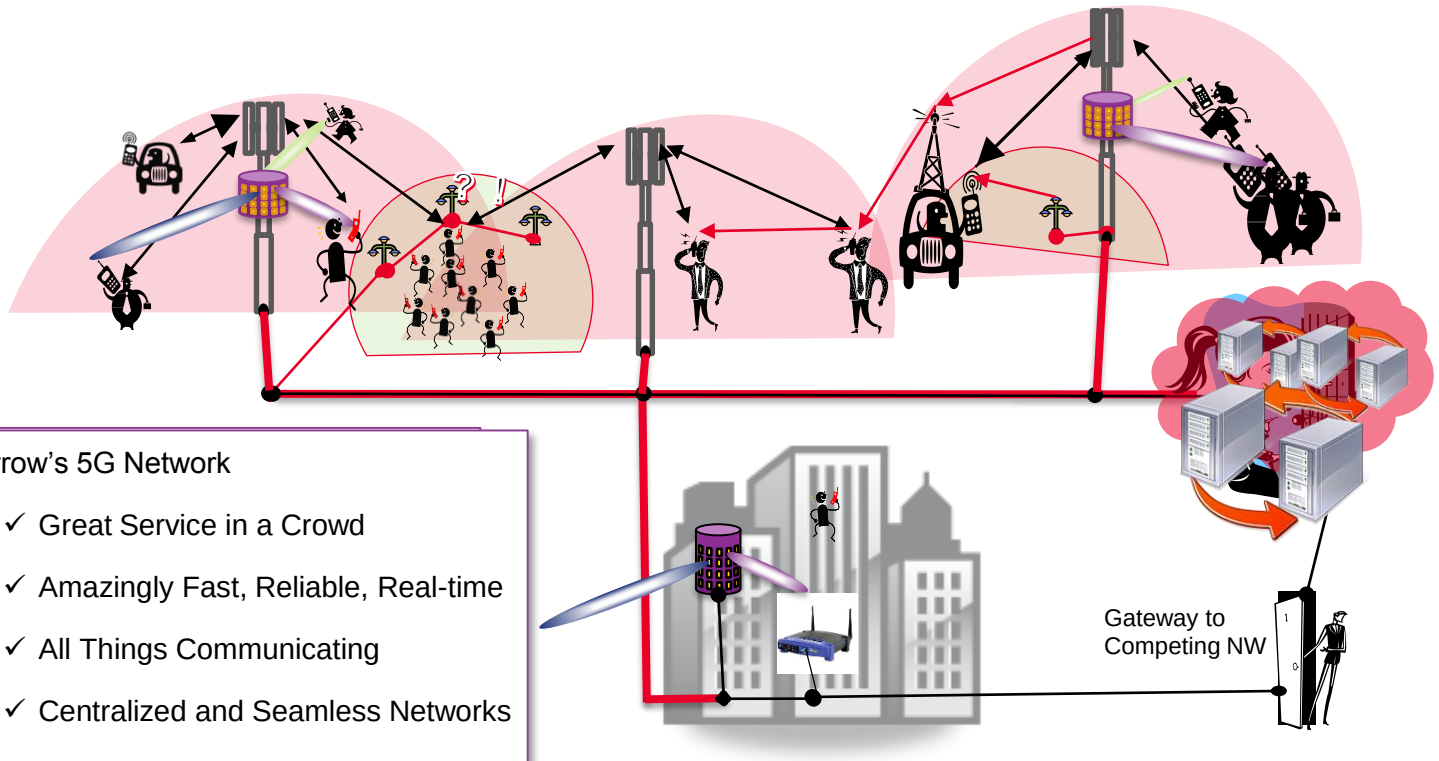
5G: A Broad Spectrum of Opportunity

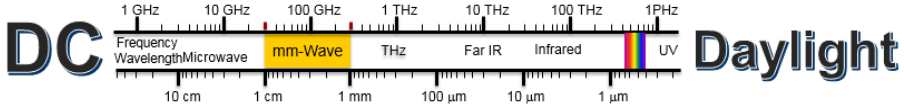
The Mobile Data Future



Tomorrow's 5G Network

- ✓ Great Service in a Crowd
- ✓ Amazingly Fast, Reliable, Real-time
- ✓ All Things Communicating
- ✓ Centralized and Seamless Networks

5G Enabling Technologies



Evolution of existing technology + Revolution of new technology

New Technology (Revolution)

- Microwave and mmWave frequency bands
- Wide bandwidth – up to 2 GHz or wider
- Massive MIMO - Number of BS antennas >> Number of UE's
- New waveforms and new radio access technology (NR)
- In-band full duplex
- Software based network architecture: SDN and NFV

Evolution of existing technology (Sub-6 GHz)

- Evolution of current cellular technologies – LTE-A/LTE-A Pro
  - Example: license assisted access (LAA); enhancement to machine type communication (MTC) or NB-IoT
- New waveforms and new radio access technology (NR)
- New frequency bands below 6 GHz
- Ultra-dense networks – small cells and WLAN access points
- Evolution of RAN architecture (Advanced C-RAN)

With tight interworking between exiting technologies and the new technologies

Increasing Frequencies: Challenge and Opportunity

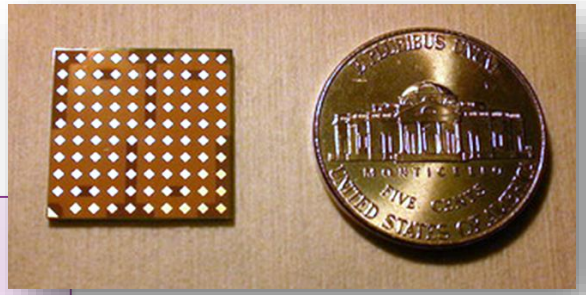
Free-space Path Loss

$$Power_{RX} = Power_{TX} + AntGain_{RX} + AntGain_{TX} - 20log_{10}(4\pi R) - 20log_{10}\left(\frac{f}{c}\right)$$

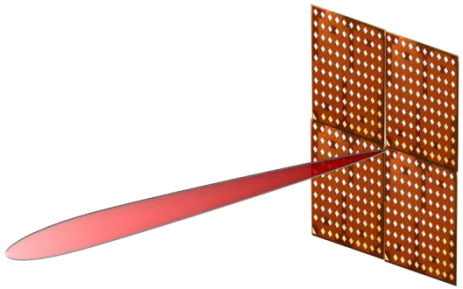
Distance Frequency

In words. For a given distance, as the frequency increases, the received power will drop unless offset by an increase in some combination of transmit power, transmit antenna gain, and receive antenna gain.

The decrease in power as a function of frequency is caused by the decrease in the antenna aperture.



IBM 94 GHz Array
Can Tile for Larger Arrays
IBM Press Release, June 2013



The Good News:

- Higher frequency antennas 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:

- Increased complexity with more elements
- Multiple antenna arrays required for spherical coverage
- Discovery and Tracking (mobile devices)

New Air Interface for 5G

– New air interface for sub-6 GHz and > 6 GHz are being researched for the various 5G use cases

– New waveforms, modulation formats and multiple access schemes are being researched for both < 6 GHz and > 6 GHz

Duplex	Multiple Access Scheme	Waveform Type	Modulation Format

• FDD
• TDD
• Flexible Duplex
• Full Duplex
	• OFDMA
	• SCMA
	• NOMA
	• MUSA
	• plus more…
		• Single-carrier
		• Multi-carrier:
		  • CP-OFDM
		  • FBMC
		  • UFMC/UF-OFDM
		  • GFDM
		  • plus more
			• OQPSK
			• QAM
			• New constellation mapping
			• plus more…

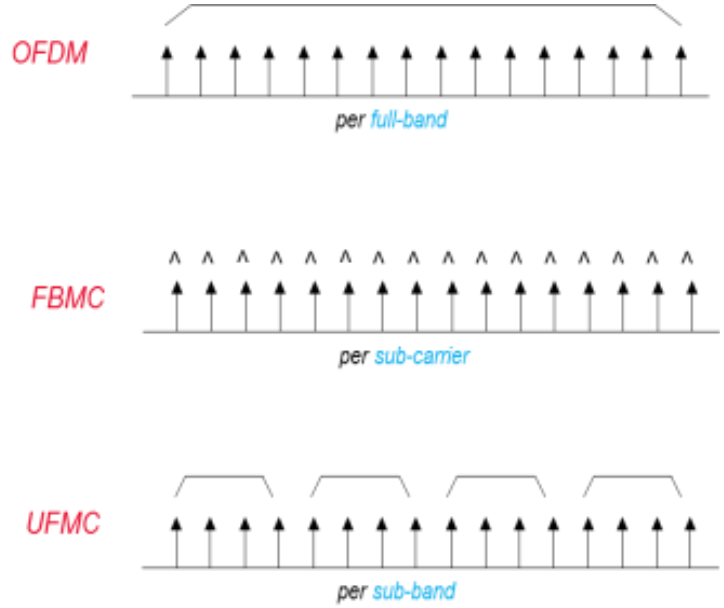
Note:
- For < 6 GHz, it is most likely both FDD and TDD will be deployed vs. TDD only in mmWave
- For < 30 GHz, it is most likely multi-carrier waveforms such as OFDM, FBMC, UFMC will be deployed vs. single carrier waveform in mmWave bands

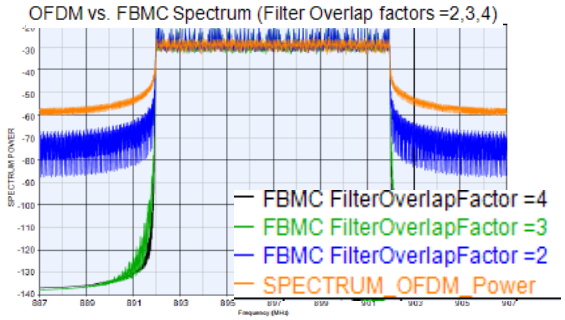
- Orthogonal Frequency Division Multiplexing(OFDM)
- Filter Bank Multicarrier(FBMC)
- Universal Filtered Multicarrier(UFMC)
- Universal filtered OFDM (UF-OFDM)
- General Frequency Division Multiplexing (GFDM)
- Orthogonal Frequency Division Multiple Access (OFDMA)
- Non-orthogonal Multiple Access (NOMA)
- Sparse Code Multiple Access (SCMA)
- Multi-User Shared Access (MUSA)

Candidate Waveforms

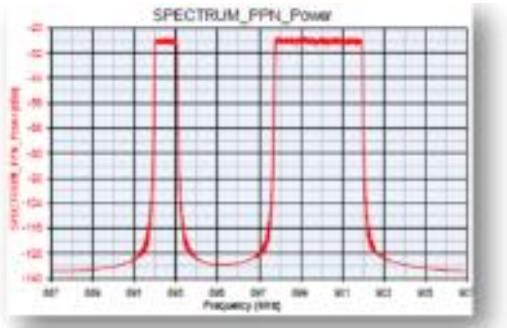
Multicarrier waveforms and filter operation

- **Cyclic Prefix based OFDM (CP-OFDM)** – used in LTE
  - Filter per full-band, uses cyclic prefix to separate symbols
  - Not efficient for small packets
- **Filter Bank Multicarrier (FBMC)**
  - Filter per subcarrier, reduced side lobes, no cyclic prefix
  - Offset-QAM (OQAM) used to achieve orthogonality
- **Universal Filtered Multicarrier (UFMC)**
  - Also known as universal filtered OFDM (UF-OFDM)
  - Filter per sub-band, reduced side lobes, no cyclic prefix
  - Claim to be efficient for both large and small packets
  - QAM may be used for modulation

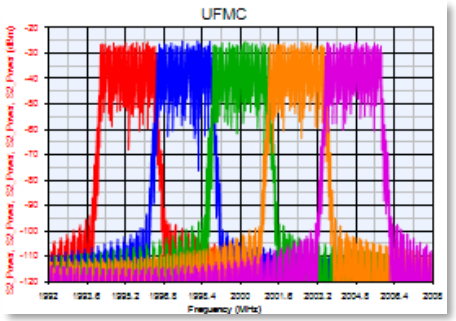




OFDM vs. FBMC using different filter overlap factor



FBMC fragmented spectrum



UFMC multiplex of sub-bands

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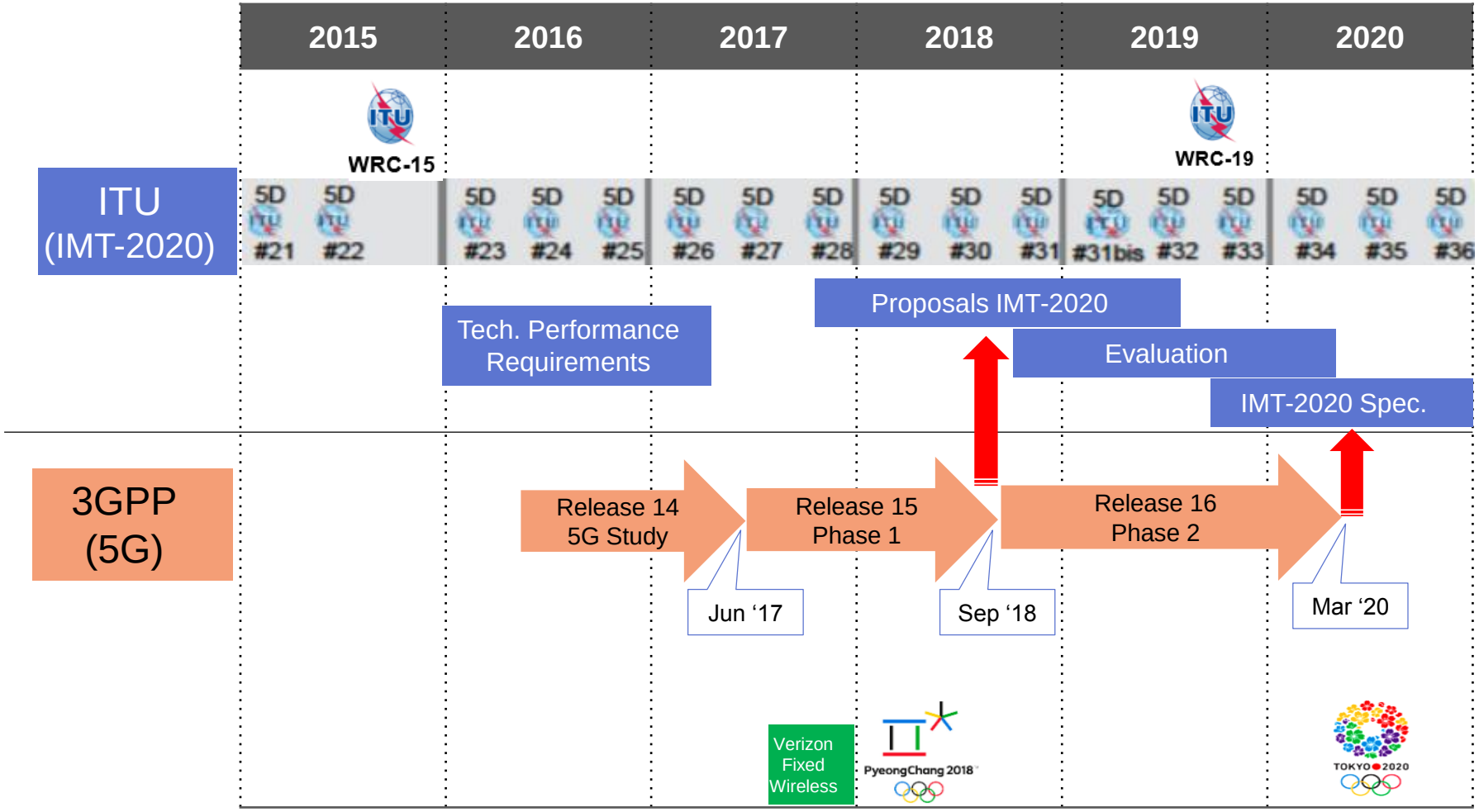
5G Timeline in ITU-R (WP5D) and 3GPP



mmWave: 5G Frequency bands > 6GHz

Frequency	Europe	FCC (Jun 2016)	ITU (Oct 2015) For study	Japan	Korea
28GHz (25-27GHz)	24.25-27.5 ~~27.5-28.5~~	27.5-28.35 BW 425MHzX2	24.25-27.5GHz	27.5~28.5 GHz	26.5~29.5 GHz
32GHz					
37GHz		37.0-38.6 BW 400MHzX4	37-40.5GHz		
39GHz		38.6-40.0 BW 200MHzX7			
40.5-43.5GHz	UK at least	FFS	42.5-43.5GHz		
45.5-48.9GHz	UK at least		45.5-47GHz		
47.2-50.2GHz					
50.4-52.6GHz					
57-66GHz		59.3-71GHz (extend ISM—unlicensed)			
64-71GHz	66-71GHz		66-76GHz		
71-76GHz	UK at least				
81-86GHz					

Most Likely Uses of Spectrum as of Sept 2016

- Significant investment in EMBB *Mobile, Multiple Access* <40GHz due to cost and simplicity.
  - 28GHz: Korea, Japan, and USA
  - 37-39 GHz USA and perhaps more likely for Europe
  - 24-27GHz : Europe
- 45GHz: Focus for 802.11aj in China
- 57-86GHz Bands more likely for high-speed point-to-point and extensions of ISM-based WiFi

Examples of Public Activity (Updated Summer 2016)

- FCC Announced rules on mmWave proposals 14 July 2016
- Ericsson will provide 28GHz system for SKT and 15GHz system for CMCC
- AT&T, Verizon, T-Mobile filed for experimental licenses (3.5, 3.7, 15, 28, 37, 39GHz)
- KT will provide trial service at 2018 Winter Olympic game with 28GHz
- Most large players demonstrating high-rate capabilities from 15-90GHz

3GPP 5G overview

3GPP Scenarios & KPIs for NR(New Radio)

3GPP TR 38.913 V14.2.0 (2017-03)

12 Deployment scenarios					
Indoor hotspot	Dense urban	Rural	Urban macro	High speed	Urban coverage for massive connection
Extreme long distance coverage	Highway scenario	Commercial Air to Ground scenario	Light aircraft scenario	Satellite extension to Terrestrial	Urban grid for connected car

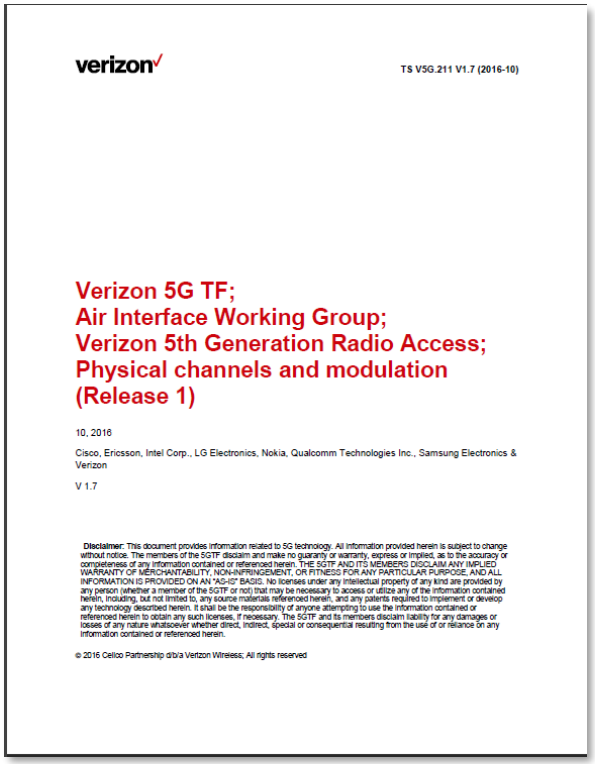
URLLC mMTC eMBB

	19 KPIs ➔ Value		
1	Peak Data Rate ➔ DL: 20Gbps UL: 10Gbps	11	Area Traffic Capacity ➔ Factored by SE, site density, BW
2	Peak Spectral Efficiency ➔ DL: 30bps/Hz UL: 15bps/Hz	12	User Experience Data Rate ➔ Factored by 5% SE & BW
3	Bandwidth ➔ Up to IMT-2020 Requirement	13	Reliability(eV2X) ➔ $(1\text{-}10^{-5})$ with latency 2~10ms
4	Control Plane Latency ➔ 10ms	14	Coverage ➔ MCL:164dB(160bps) Function of data rate
5	User Plan Latency URLLC ➔ 0.5ms eMBB: 4ms	15	UE Battery Life ➔ 10 years (15y is desirable)
6	Latency for Infrequent Small Packets ➔ No worse than 10s	16	UE Energy Efficiency ➔ Qualitative
7	Mobility Interruption Time ➔ 0ms	17	Mobility ➔ 500km/h
8	Inter-system Mobility ➔ btw IMT-2020 & IMT	18	Connection Density ➔ 10^6 devices/km2
9	Reliability(URLLC) ➔ $(1\text{-}10^{-5})$ with latency 1ms	19	5th Percentile User Spectral Efficiency ➔ 3x IMT-Advanced
10	Cell/TRP Spectral Efficiency ➔ 3x IMT-Advanced		

Verizon Pre-5G Overview

www.5gtf.org

Specifications are available for download from this page


verizon

TS V5G.211 V1.7 (2016-10)

Verizon 5G TF;
Air Interface Working Group;
Verizon 5th Generation Radio Access;
Physical channels and modulation
(Release 1)

10, 2016

Cisco, Ericsson, Intel Corp., LG Electronics, Nokia, Qualcomm Technologies Inc., Samsung Electronics & Verizon

V 1.7

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Verizon 5g Technology Forum consists of Cisco, Ericsson, Intel, LG, Nokia, Qualcomm, and Samsung to utilize 28GHz band

KT 5G-SIG(Special Interest Group)

https://www.kt.com/biz/kt5g_02.jsp

Specifications are available for download from this page

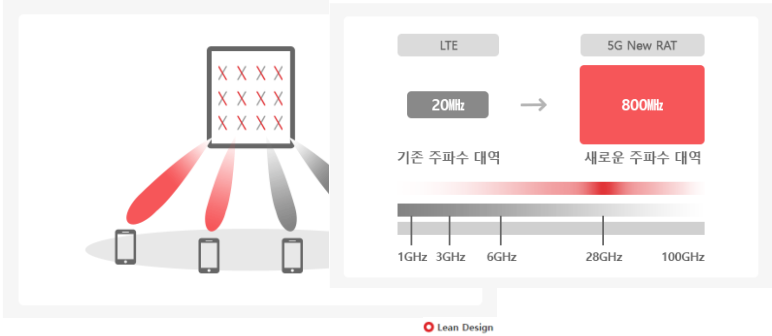
KT 5G-SIG(Special Interest Group) 구성

KT는 2018 평창 동계올림픽에서 세계최초 5G 시범 서비스를 선보이기 위해 글로벌 파트너들과 함께 2015년 9월 KT PyeongChang 5G Special Interest Group(KT 5G-SIG)를 구성하였습니다.
글로벌 주요 제조사로 구성된 KT 5G-SIG 참여사와 협력을 통해 2016년 3월 세계최초 5G 공통 물리계층 규격(Layer1)을 완성하였으며, 같은 해 6월에는 상위계층 규격(Layer2,3)을 포함한 전체규격을 완성하였습니다.
KT는 KT 5G-SIG 규격 기반으로 평창 5G 시범서비스를 위한 5G 시스템/단말 개발을 추진하고 있습니다. 이러한 5G 시범망은 5G 핵심 요소 기술들의 성능 검증을 위한 테스트 플랫폼으로도 활용될 계획입니다.

KT 5G-SIG 규격

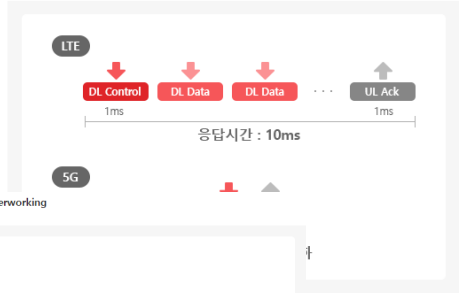
번호	제목	다운로드
1	5G.201(KT 5th Generation Radio Access; Physical layer)	다운로드
2	5G.211(KT 5th Generation Radio Access; Physical channels and modulation)	다운로드
3	5G.212(KT 5th Generation Radio Access; Multiplexing and channel coding)	다운로드
4	5G.213(KT 5th Generation Radio Access, Physical layer procedures)	다운로드
5	5G.214(KT 5th Generation Radio Access, Physical layer measurements)	다운로드
6	5G.321(KT 5th Generation Radio Access, Medium Access Control protocol)	다운로드
7	5G.322(KT 5th Generation Radio Access, Radio Link Control protocol)	다운로드
8	5G.323(KT 5th Generation Radio Access, Packet Data Convergence Protocol)	다운로드
9	5G.331(KT 5th Generation Radio Access, Radio Resource Control)	다운로드
10	5G.300(KT 5th Generation Radio Access, Overall Description)	다운로드

빔포밍(BeamForming)

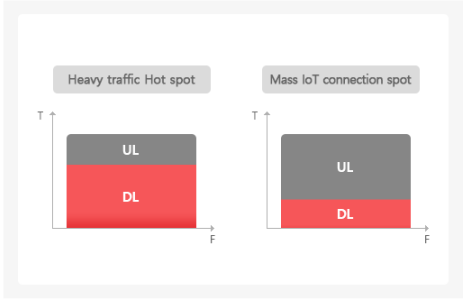


초광대역 밀리미터파

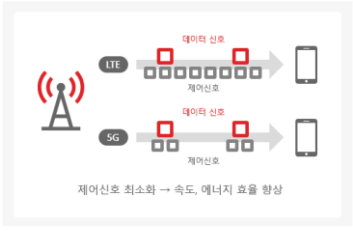
Self-contained 구조



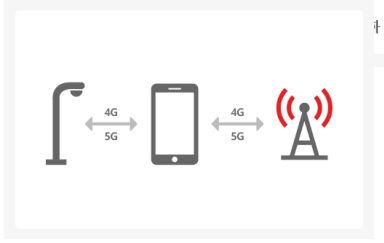
Dynamic TDD



Lean Design



4G-5G Interworking



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Verizon vs KT 5G vs 3GPP NR

3GPP TR 38.802 V14.0.0 (2017-03)

	Verizon Pre-5G	KT 5G-SIG	3GPP NR - not finalized
Duplexing	Dynamic TDD	Dynamic TDD	FDD, Dynamic TDD
Beamforming	Yes	Yes	Yes
Frequency bands	28 GHz	28 GHz, 39 GHz	Up to 100 GHz
Carrier Bandwidth	100 MHz	100 MHz	Sub-6GHz - 100 MHz > 6 GHz (400, 800, 1000 MHz)?
Carrier aggregation	8	8	8 – 32
Waveform	OFDMA	OFDMA	OFDMA (DL&UL), SC-FDMA (opt UL), other waveforms for mMTC & high freq.
Modulation	Up to 64QAM	Up to 64QAM	Up to 256QAM (1024QAM?)
Use cases	eMBB fixed access	eMBB mobility	eMBB, mMTC, URLLC
Network deployment	Standalone	Non-Standalone (with LTE)	Standalone, Non-standalone
Multiplexing of different numerologies	No	No	Yes
Spectrum	Licensed	Licensed	Licensed, unlicensed, shared acce ss
Channel coding	TBCC, LDPC Turbo Code (optional)	TBCC, LDPC	LDPC (for eMBB data), Polar Cod e (for eMBB control)

Numerology = LTE x 5

Sampling frequency = 153.6 MHz (30.72 MHz x 5)

Subcarrier spacing = 75 kHz (15 kHz x 5)

Carrier bandwidth = 100 MHz (20 MHz x 5)

https://www.kt.com/biz/kt5g_02.jsp

www.5gtf.org

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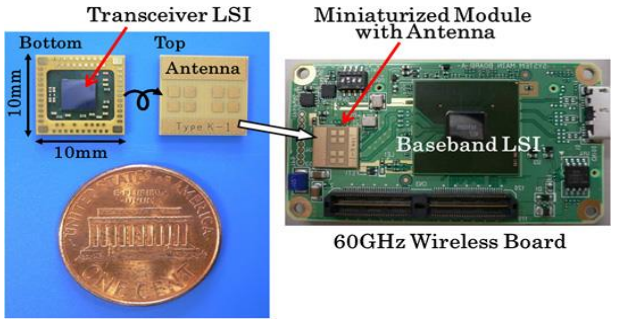
mmWave Design Challenges

High Frequency	High Bandwidth	High Path Loss	High Data Rate
Phase Stability	High IF Converters (use 2nd Nyquist)	Directional Antennas Usually Required	Power consumption
Amplifier Efficiency	I and Q channel match over frequency	Large codebook space for Beam Steering	Algorithm Complexity
Output Power	Integrated Noise Power	Beam forming complexity	Prototyping (FPGA's usually not fast enoug h)
Antenna Complexity	IF/RF Flatness	Robust Modulation and Coding (MCS)	IO (memory, interfaces to CPU's etc)
Quadrature Errors (Homodyne)	A/D and D/A Converters (power consumption)	Discovery and Tracking affect MAC and MCS	High sample-rate data to/from converters

Measurement Challenges for 5G

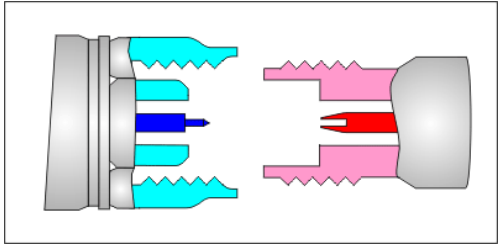
- Unknown mm-Wave channels
  - Directional antennas required. New concept for mobile devices
- Too sensitive with measurement conditions
  - Very delicate with cables and connections
  - High Frequency : High Path loss/ Phase Stability
- Wider bandwidth for Large capacity data communication
  - I and Q channel match over frequency
  - Integrated Noise Power
  - RF/IF Flatness
  - Traditional instrument can not provide sufficient BW
- mm-Wave multiple Antenna Test : Massive MIMO
- Small size of DUT
  - No connector RF Access
  - Integrated PA and antenna have no RF test connectors



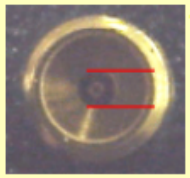
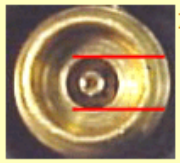
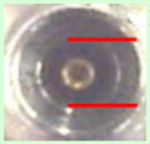
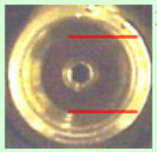
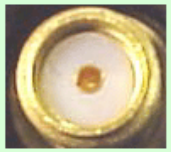
http://news.panasonic.com/global/press/data/2013/02/en130220-2/en130220-2.html

mmWave Connectors

Careful what you mix and match



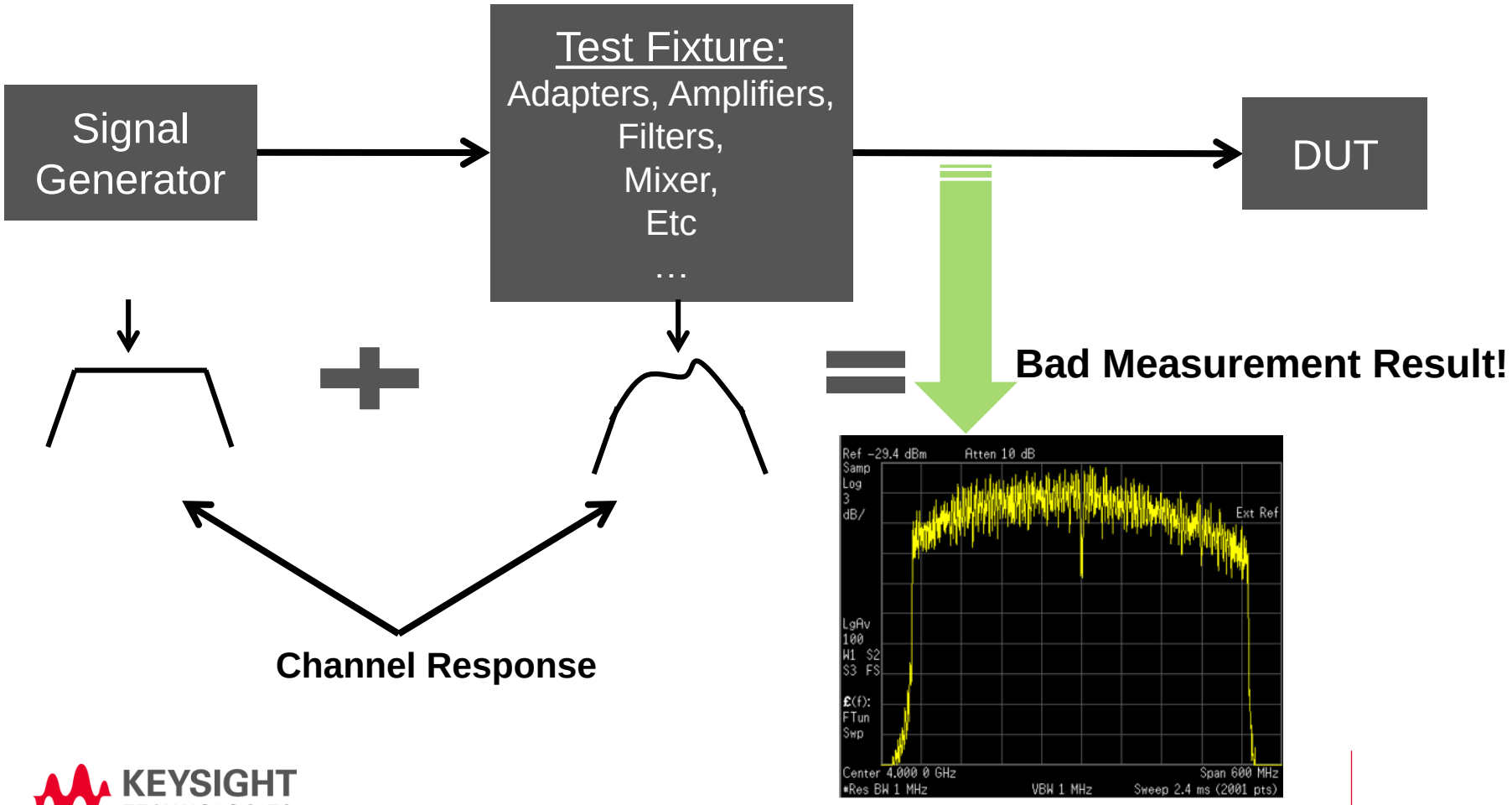
- 2.92 and 3.5 mm connectors use the same center pin. You can use them together
- Large, flat face connectors on instruments are rugged. Use with *connector savers*

Connector Type	Frequency Range	Mates with...
 1.0 mm	To 110 GHz	1.0 mm
 1.85 mm	To 70 GHz	2.4 mm
 2.4 mm	To 50 GHz	1.85 mm
 2.92 mm	To 40 GHz	3.5mm and SMA
 3.5 mm	To 34 GHz	2.92 mm and SMA
 SMA	To 24 GHz	2.92 mm and 3.5 mm

KEYSIGHT TECHNOLOGIES

Measurement Challenges – System Calibration 1/2

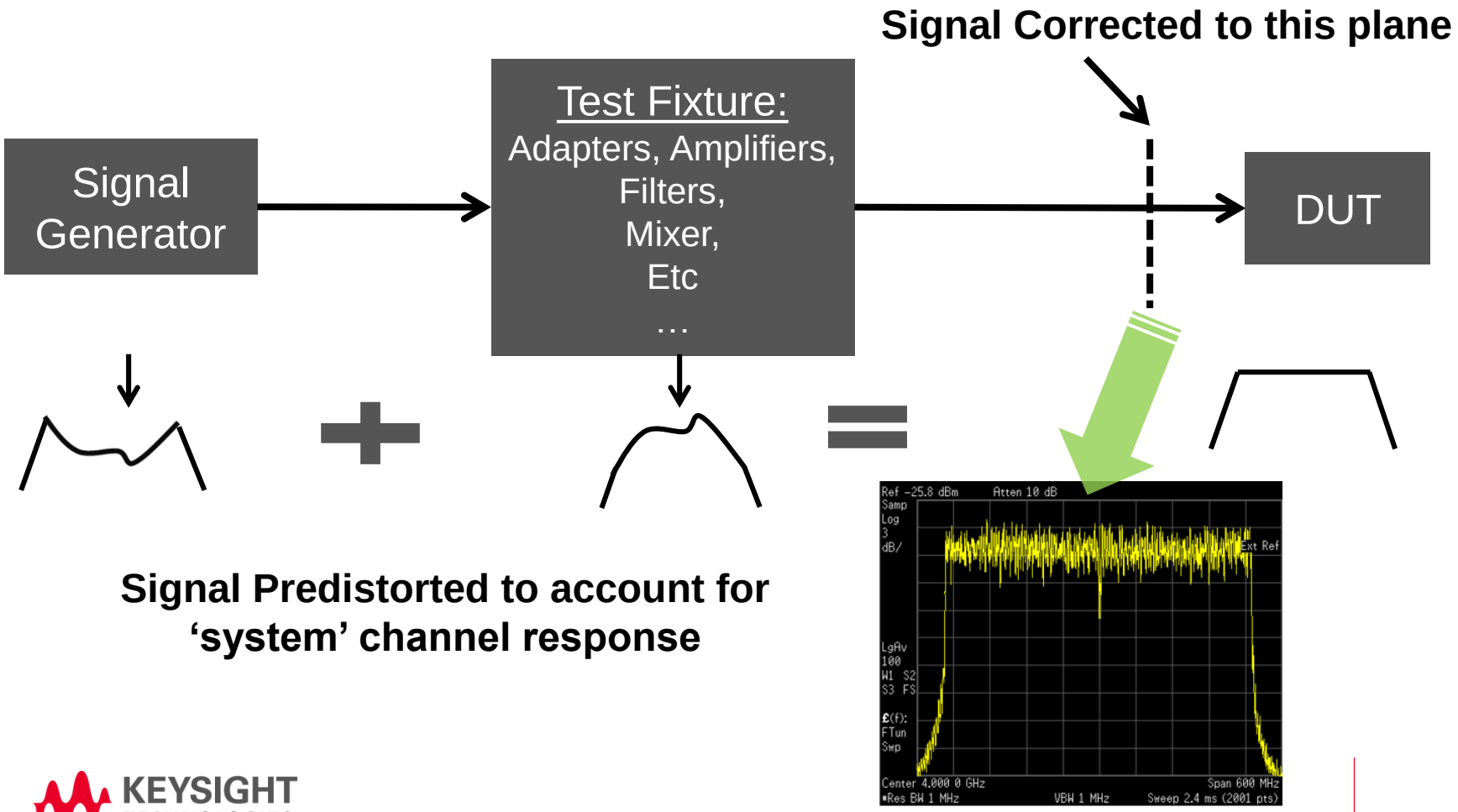
Measurement required for
a wide range of modulation bandwidths from several MHz to a few GHz and
a wide range of frequency bands, from RF to microwave to millimeter-wave



UWB - 500 MHz Bandwidth

Measurement Challenges – System Calibration 2/2

Measurement required for
a wide range of modulation bandwidths from several MHz to a few GHz and
a wide range of frequency bands, from RF to microwave to millimeter-wave



Signal Predistorted to account for ‘system’ channel response

UWB - 500 MHz Bandwidth

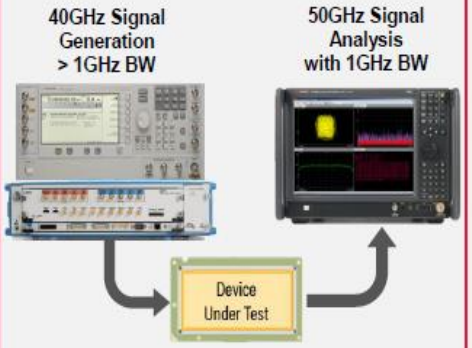
Agenda

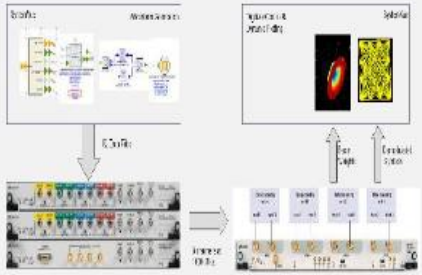
- 5G Vision & Candidate Technologies
- 5G Timeline & Standard update
- mmWave System considerations
- 5G Solution in Keysight
  - ✓ HARDWARE+SOFTWARE+PEOPLE=5G INSIGHTS
  - ✓ Measurement examples

Keysight Test Solutions for early 5G Research

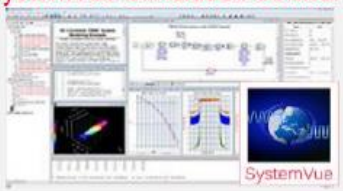
Benchtop and modular signal generation and analysis + channel emulation

Wideband RF/μW/mmWave Generation & Analysis	Wideband mmWave Analysis	Channel Sounding mmWave, Wide BW & MIMO	Massive MIMO
5G Waveform Generation & Analysis Testbed Reference Solution	E-Band Signal Analysis Reference Solution	Channel Sounding Reference Solution	Real-time beamforming signal generation & analysis



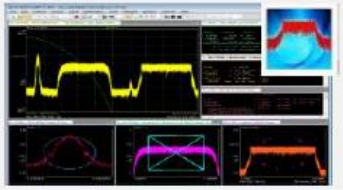


SystemVue Simulation Software



Signal Studio Software

89600 VSA Software



5G channel emulation

HARDWARE+SOFTWARE+PEOPLE=5G INSIGHTS

KEYSIGHT TECHNOLOGIES

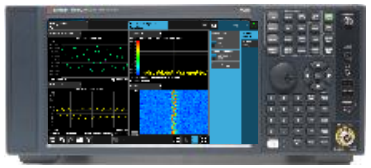
Introducing the **N9041B** UXA Signal Analyzer

Industry's **first integrated 110 GHz** signal analyzer

1st

CXA
Leading low-cost tool

- 9 kHz to 26.5 GHz,
- 25 MHz BW



EXA
Maximum value up to mmWAve

- 10 Hz to 44 GHz
- 40 MHz BW

MXA
Optimum choice for wireless

- 10 Hz to 26.5 GHz
- 160 MHz BW
- Real Time SA

PXA
Benchmark for demanding applications

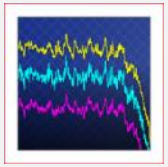
- 3 Hz to 50 GHz,
- 510 MHz BW
- Real Time SA

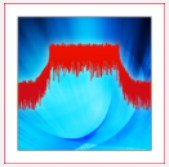
UXA
Wide-open performance

- 3 Hz to 110 GHz*
- 5 GHz BW with external oscilloscope
- 1 GHz internal BW
- Real Time SA – 255 MHz

Download your next insight

X-Series applications
Ready-to-use measurements





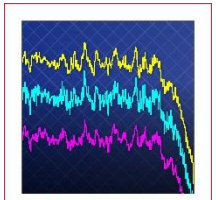
89600 VSA software
Comprehensive demodulation & vector signal analysis

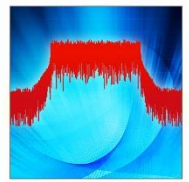
KEYSIGHT TECHNOLOGIES

*50 GHz with N9040B

The **New N9041B** UXA Signal Analyzer, **110 GHz**

- 1st — 3 Hz - **110 GHz** Continuous sweeps
- 1st — **5 GHz BW** (with external oscilloscope)
- 1st — Up to **1 GHz internal** BW
- 1st — **-150 dBm/Hz** DANL up to 110 GHz
- 1st — Dual input **rugged 2.4 mm** connector


X-Series Apps


89600 VSA

2nd rugged
2.4mm connector
3 Hz – 50 GHz

KEYSIGHT TECHNOLOGIES

Best **Dynamic Range** at **110 GHz**

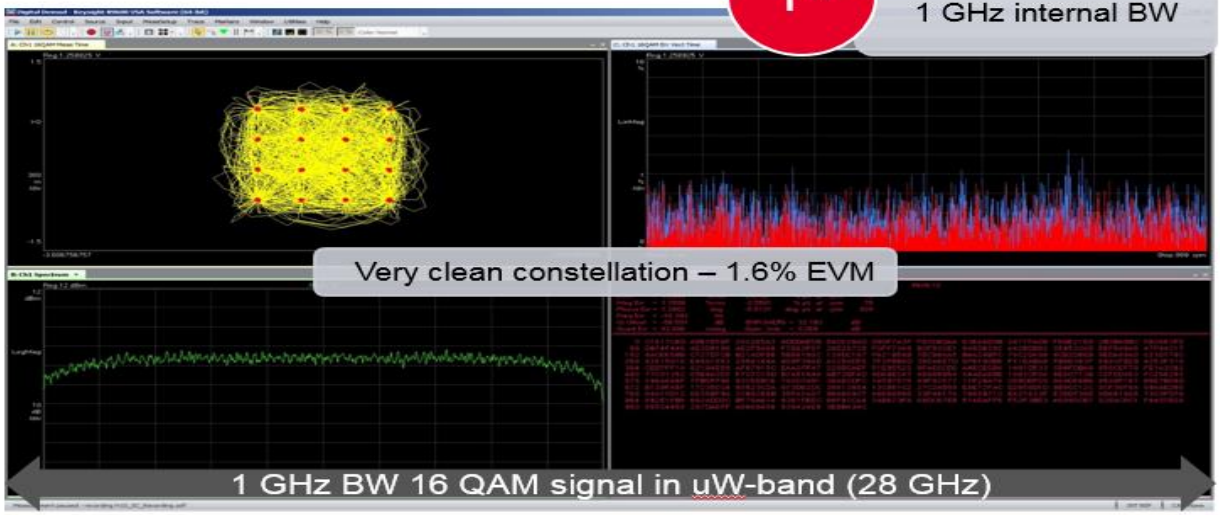
1st -150 dBm/Hz DANL up to 110 GHz

Solved – Measure small signals in presence of high power

Superb DANL without preamp = Best SEM dynamic range

Unmatched 1 GHz BW operation @ 28 GHz

1st 1 GHz internal BW



Solved – Challenging ultra wide BW measurements

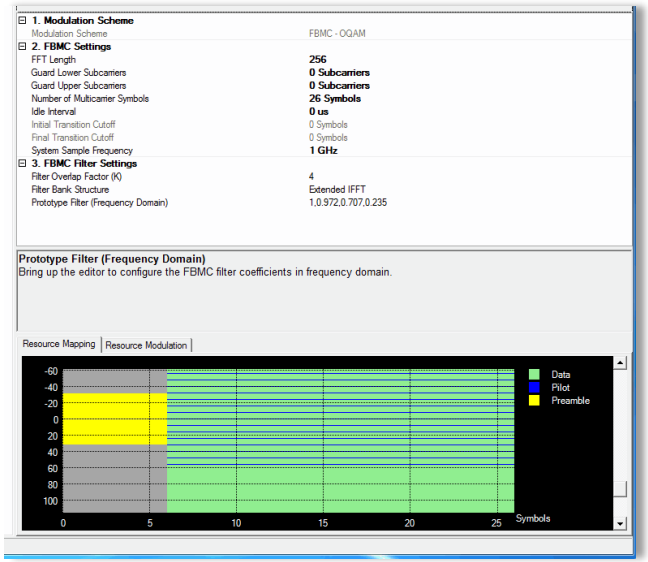
Convenient measurements of 5G, automotive and A/D signals

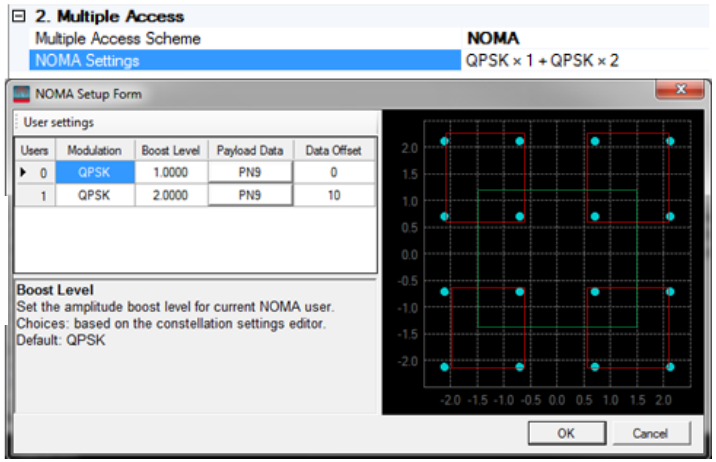
Simplify Signal Creation- 5G Candidate

N7608B Signal Studio for Custom Modulation

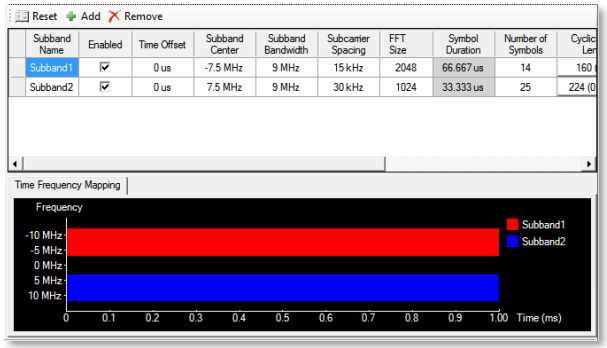
- Flexible solution supports early 5G wireless research and development
- Create emerging 5G candidate waveforms
  - ✓ FBMC, UFMC, GFDM and F-OFDM
- Multiple Access technologies Support
  - ✓ SCMA (Sparse Code Multiple Access)
  - ✓ NOMA (Non-Orthogonal Multiple Access)

FBMC





F-OFDM



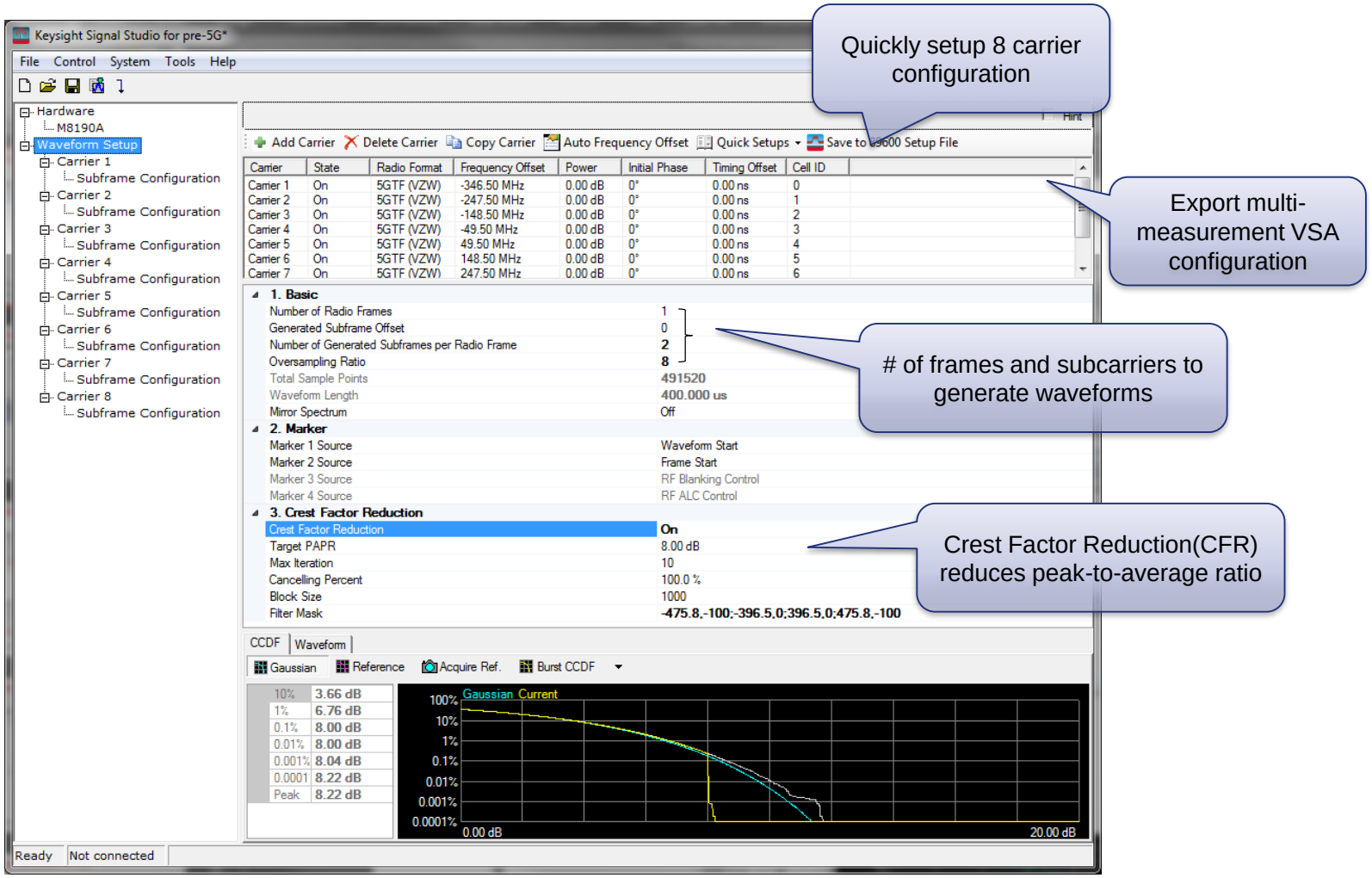
KEYSIGHT TECHNOLOGIES

New N7630C Feature Summary

Signal Generation Based on VZW Pre-5G Spec

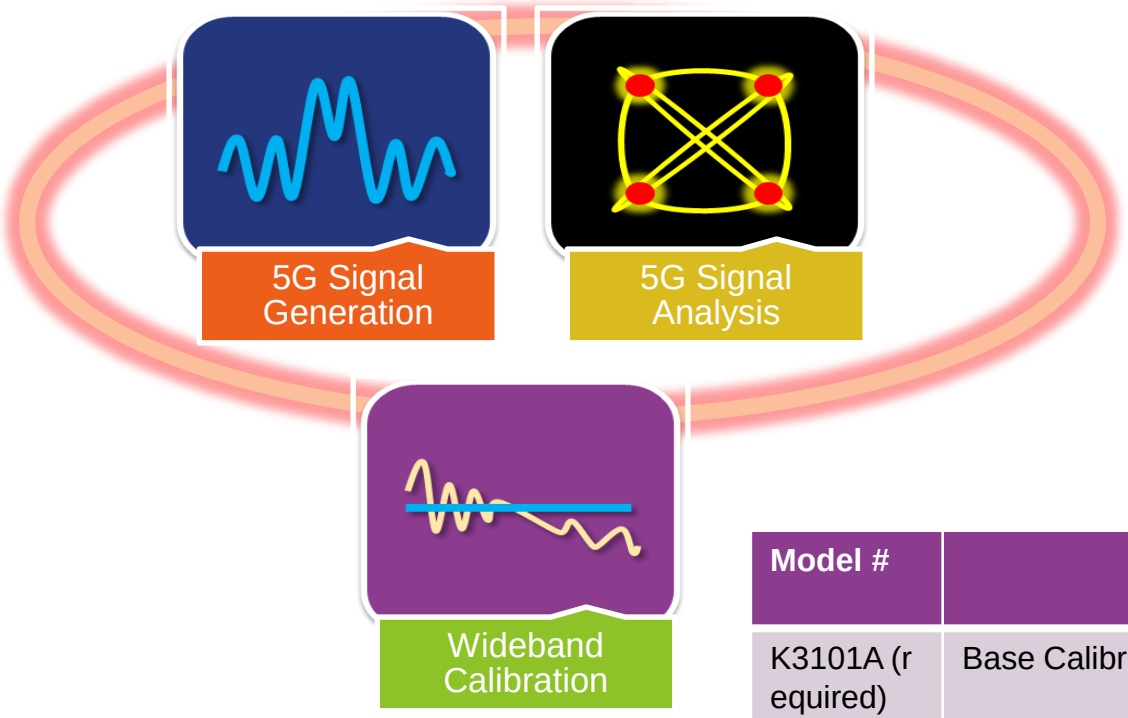
- Main PHY layer structure are implemented for signal generation
  - Support multi-user channels generation
  - Support transport channel coding for DL-SCH, UL-SCH, BCH, DCI, and UCI
    - LDPC and tail biting CC
  - DCI Auto Generation with xPDSCH and xPUSCH scheduling information
  - Multi-Antenna Transmission
    - Tx Diversity and Spatial Multiplexing
  - High Speed case for KT5G spec
- Support flexible signal configuration
  - Both single carrier and multi-carrier are supported
    - 8 Carrier Configuration Preset
- Support flexible signal configuration (Cont'd)
  - Graphical display for frame resource allocation
  - User can assign resource blocks to both downlink and uplink channels.
  - Support generating DL and UL signal at the same time.
  - Support partial generation of one radio frame
- Signal verification methods
  - User can export the demod setup of VSA software from Signal Studio for VSA demodulation.
    - Requires VSA Custom OFDM (89601B-BHF)

N7630C User Interface Overview



New 5G Software: **Keysight Signal Optimizer**

Three Functionalities in One



Model #	Description
K3101A (required)	Base Calibration, fixed perpetual license
K3102A	Digital modulation signal creation & analysis
K3103A	5G candidate modulation on LTE FDD signal creation & analysis
K3104A	5G candidate modulation on OFDM signal creation & analysis

Signal Optimizer Main Window

Toolbar provides quick access to the different settings

Calibration Button to run Cal Wizard

Context sensitive property settings

Add/Delete different waveforms, hardware easily

Block diagram provides overview of the configurations involves multiple hardware

Step 1: Rx System Calibration

Choose from U9391C/F/G Based on freq & bandwidth

Comb Generator

Test Fixture: adapters, amplifiers, filters, mixer, etc.

Signal Analyzer

Rx calibration to account for 'Signal Analyzer Test Environment' channel response

Calibration SW (Signal Optimizer)

Ref Plane

Transmitter DUT

Calibrated Signal Analyzer Test Environment

Known good receiver system to measure true DUT performance

Step 2: Tx System Calibration

Signal Source

Test Fixture:
adapters, amplifiers, filters, mixer, etc.

Calibrated Signal Analyzer Test Environment

Proprietary calibration signal

Tx calibration to account for 'Signal Source Test Environment' channel response

Calibration SW (Signal Optimizer)

Known good transmitter system to measure true DUT performance

Calibrated Signal Source Test Environment

Ref Plane

Receiver DUT

Step 3: Use Calibrated Tx and Rx Measurement System to Measure Component DUT

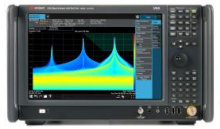
Calibrated Signal Source Test Environment

Ref Plane

Component DUT

Ref Plane

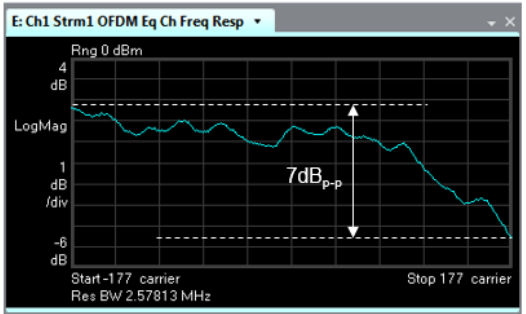
Calibrated Signal Analyzer Test Environment

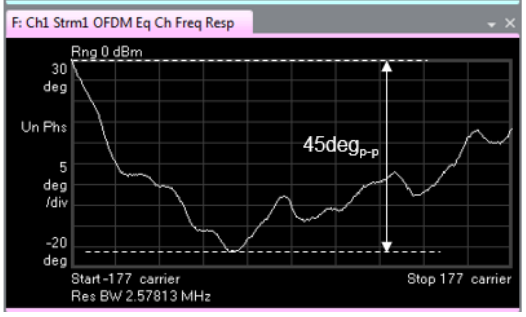


5G Waveform
(e.g. OFDM, FBMC, UFMC, GFDM, etc. …)

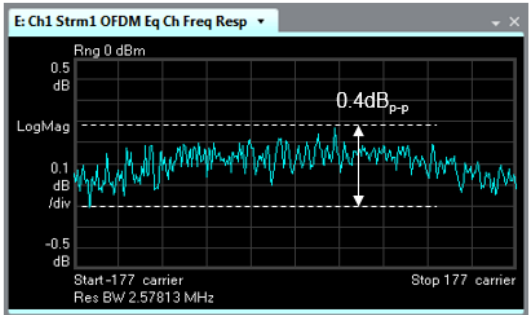
Calibration SW

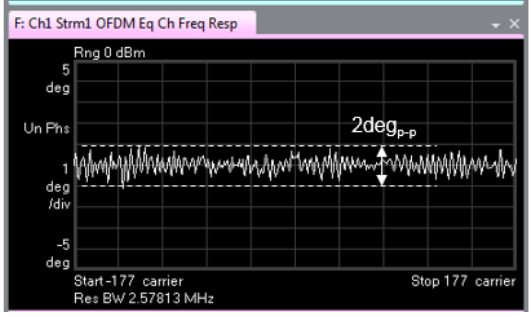
Before System Calibration
28 GHz with ~ 900 MHz Bandwidth





After System Tx and Rx Calibration
28 GHz with ~ 900 MHz Bandwidth



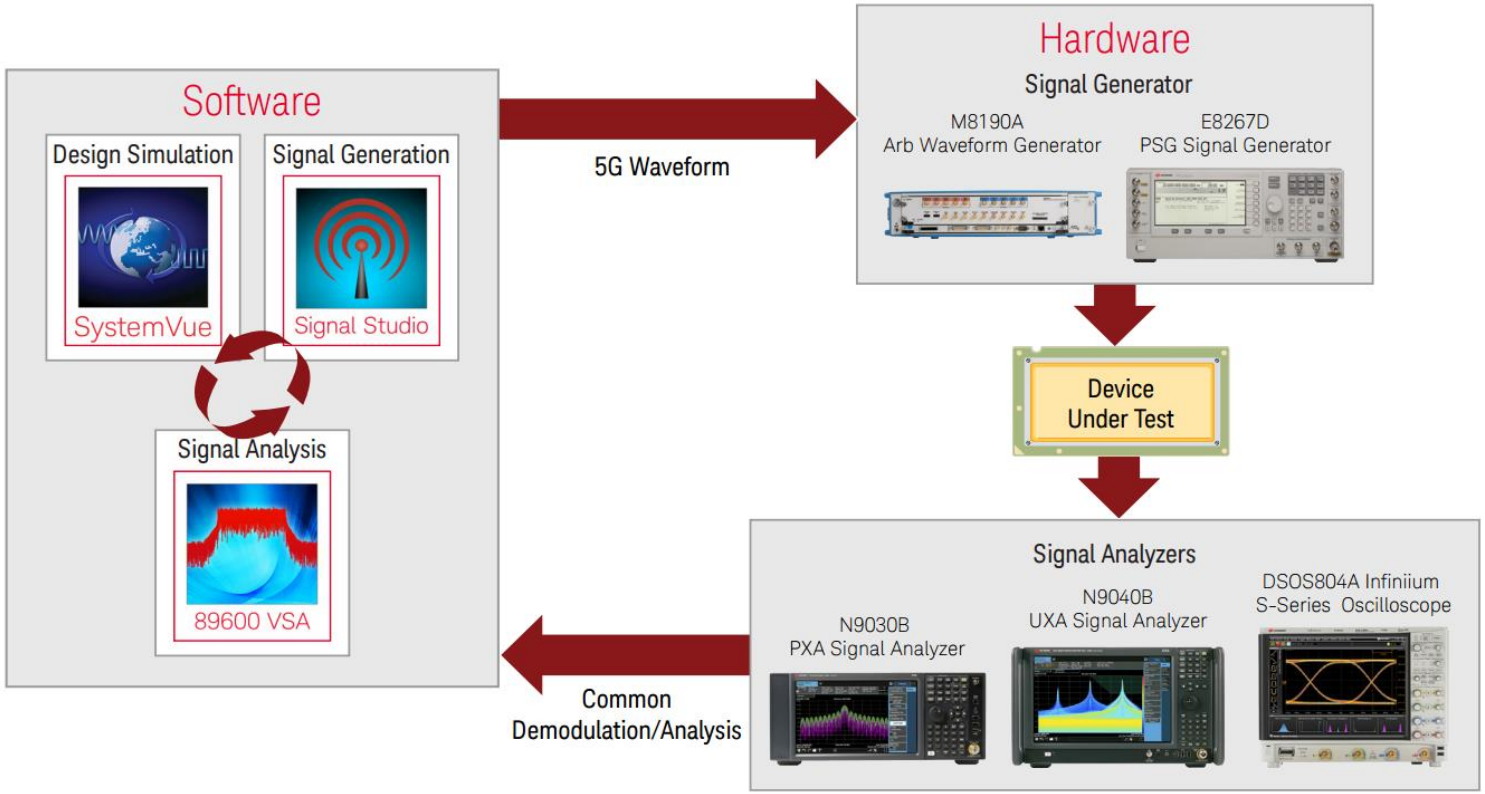


KEYSIGHT TECHNOLOGIES

5G Flexible Testbed for waveform Generation & Analysis

Flexibility is needed in three key areas of 5G research and early testing:

- Generating and analyzing new waveforms
- Supporting a wide range of modulation bandwidths, from several MHz to a few GHz
- Supporting a wide range of frequency bands, from RF to microwave to millimeter-wave



SA Frequency range : 3Hz ~ 110GHz and Analysis Bandwidth : 1 GHz (5GHz w/OSC)

SG Frequency range : 250KHz ~ 44GHz and Bandwidth : 2 GHz

KEYSIGHT TECHNOLOGIES

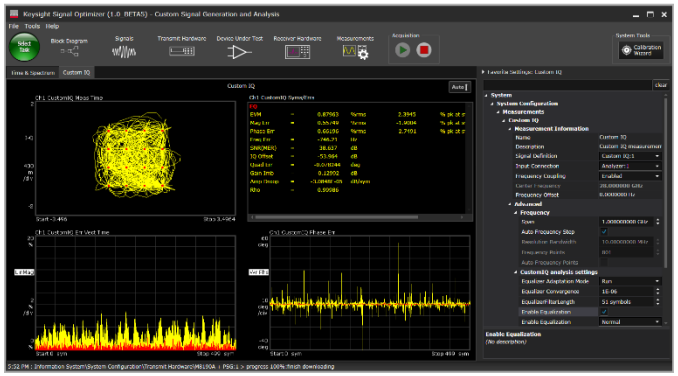
5G Testbed Reference Solution

<2 GHz Bandwidth: 50 – 110 GHz

M8190A Wideband AWG (I/Q Generation)

Waveform

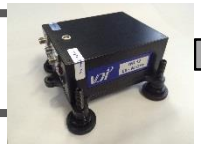
Signal Optimizer (K3101A)



E8267D PSG

Compact VDI Upconverter (V, E, W-Bands)

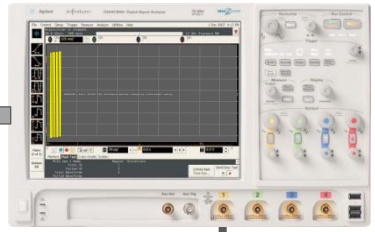
N5183A MXG (LO)



DUT

Digitized Signal

Infiniium Scope

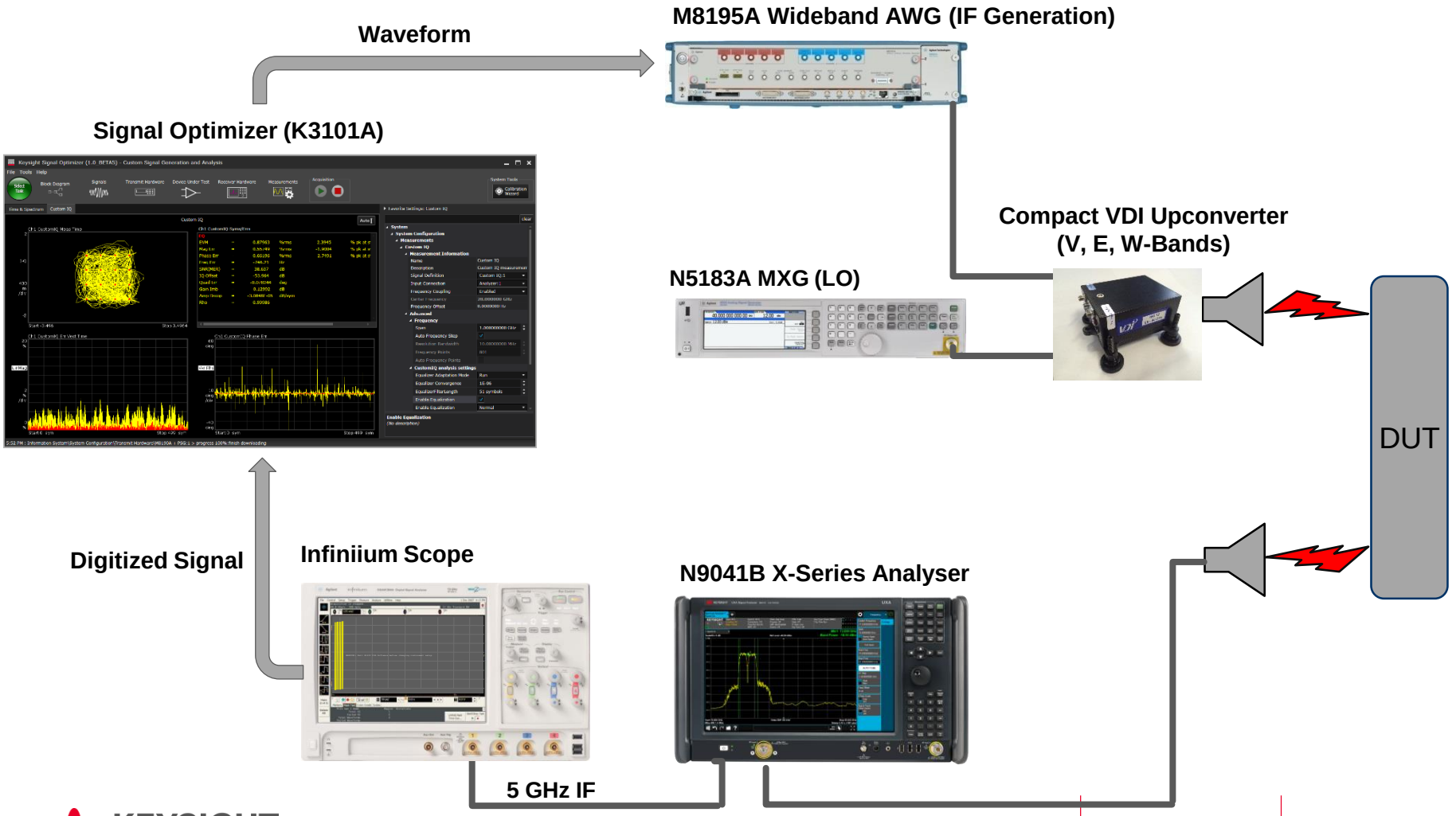


N9041B X-Series Analyser

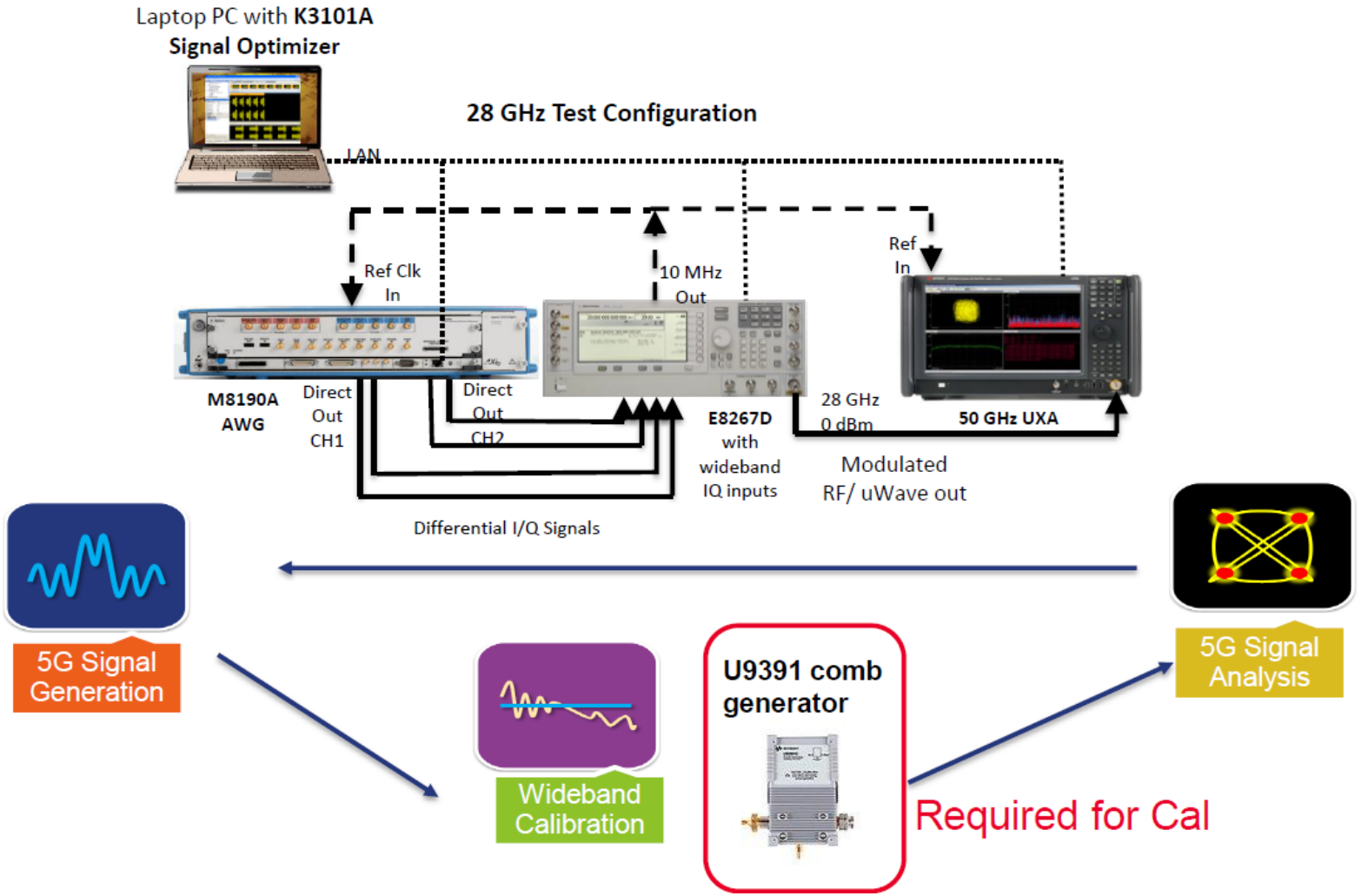
5 GHz IF

5G Testbed Reference Solution

>2 GHz Bandwidth: 50 – 110 GHz



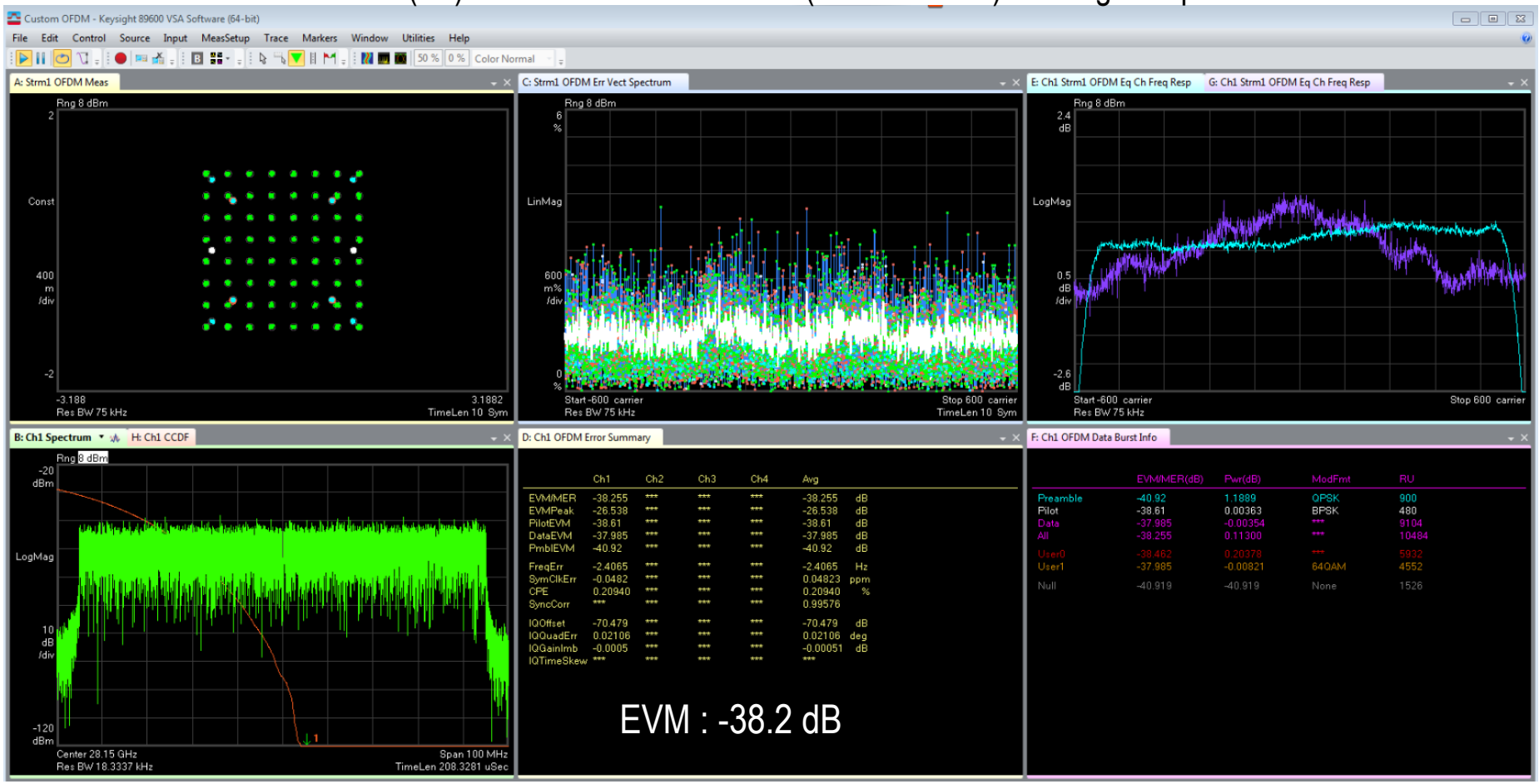
New Measurement configuration at 28GHz using 5G Flexible Testbed and Signal Optimizer



Case Study – 8 multi-carrier OFDM EVM at 28 GHz

Waveform Information :
8 multi-carrier of 100MHz component carrier, 153.6MHz sample freq., 2048 FFT, 75 KHz sub-carrier spacing, 64QAM

Measurement result for carrier (C6) of 8 multi-carries Demod (CF:28.15GHz) with Signal Optimizer



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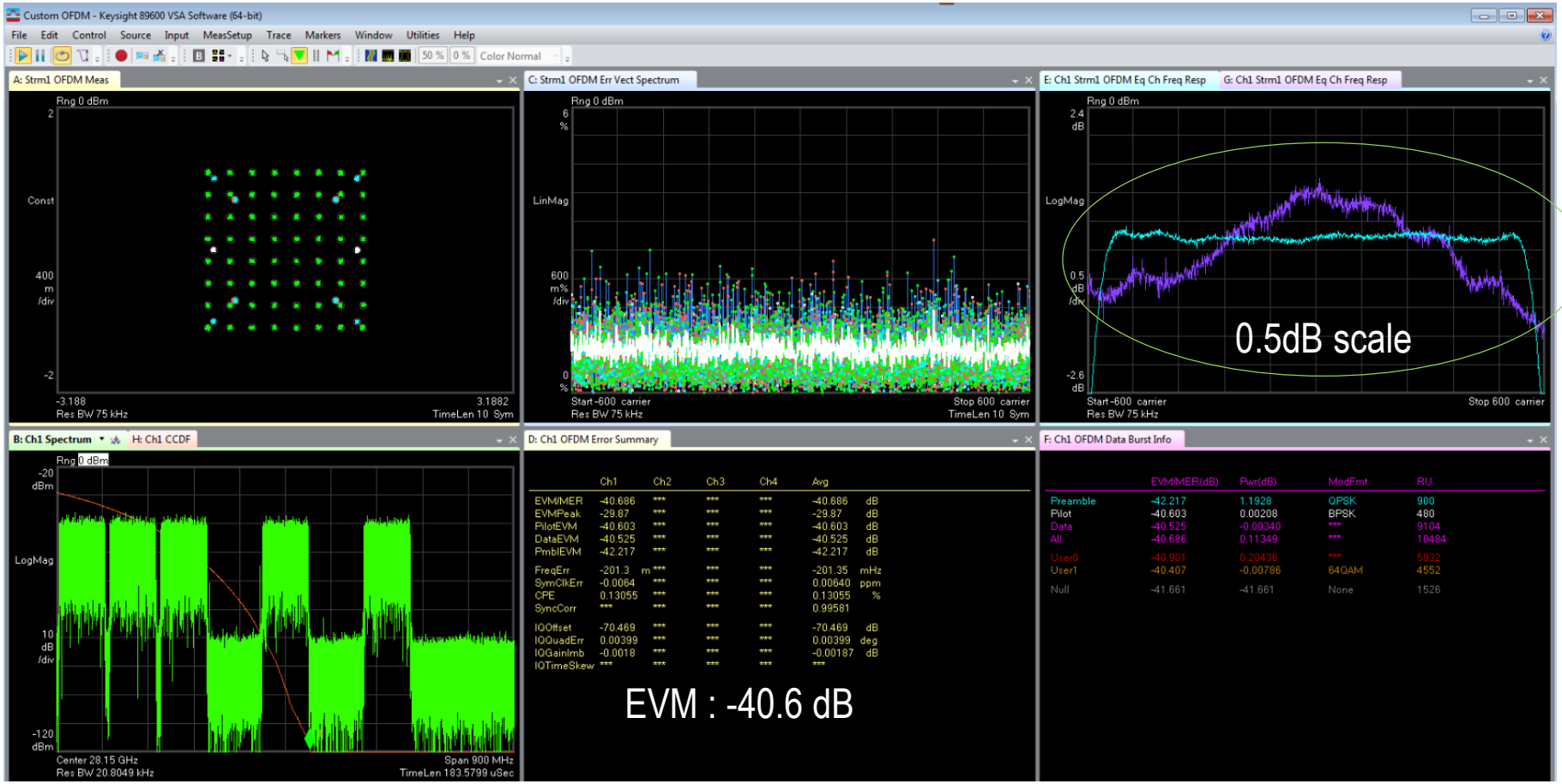
Measurement result for carrier (C6) of 8 multi-carries Demod (CF:28.15GHz) *removed C5, C7* with Signal Optimizer



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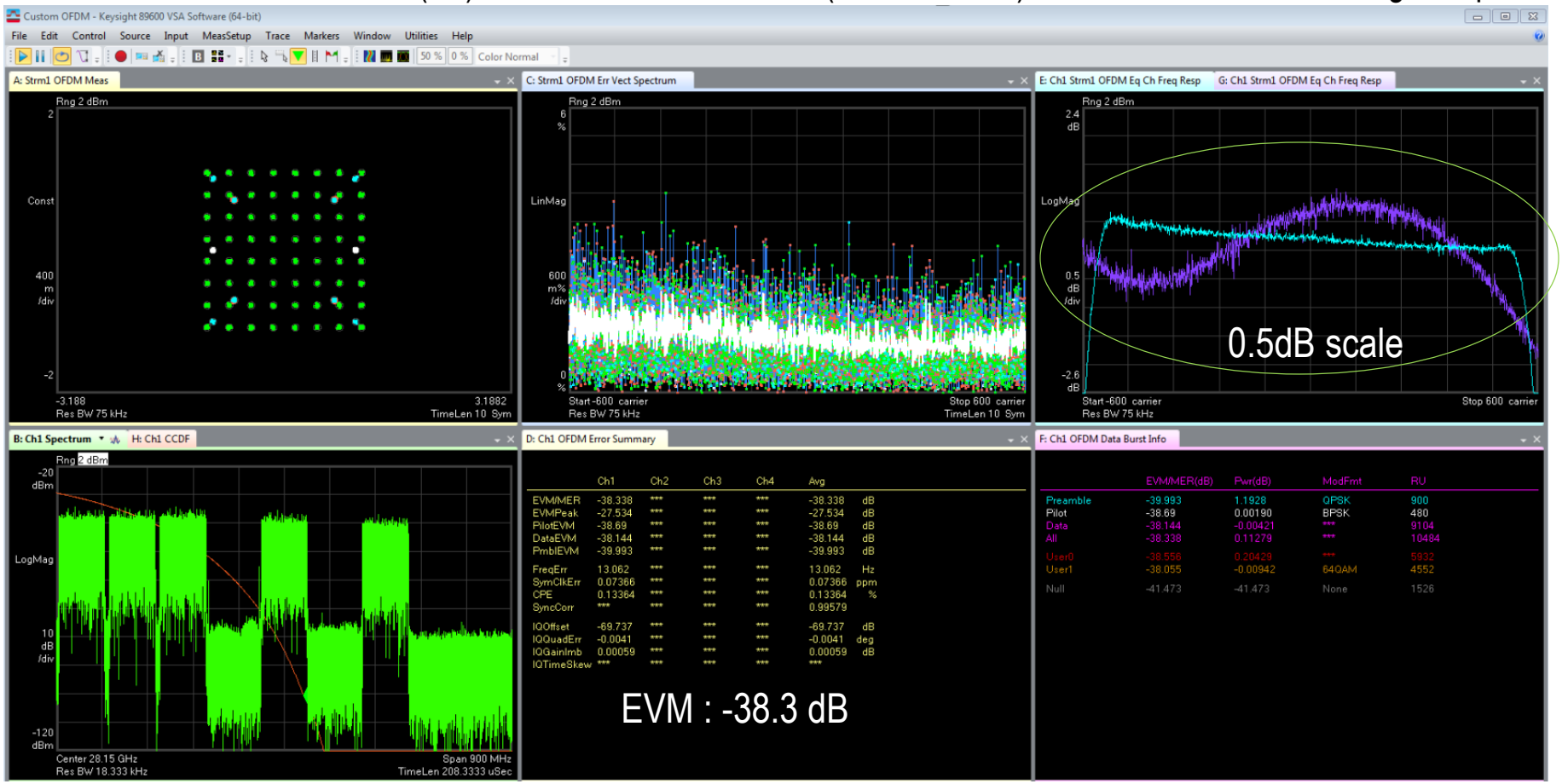
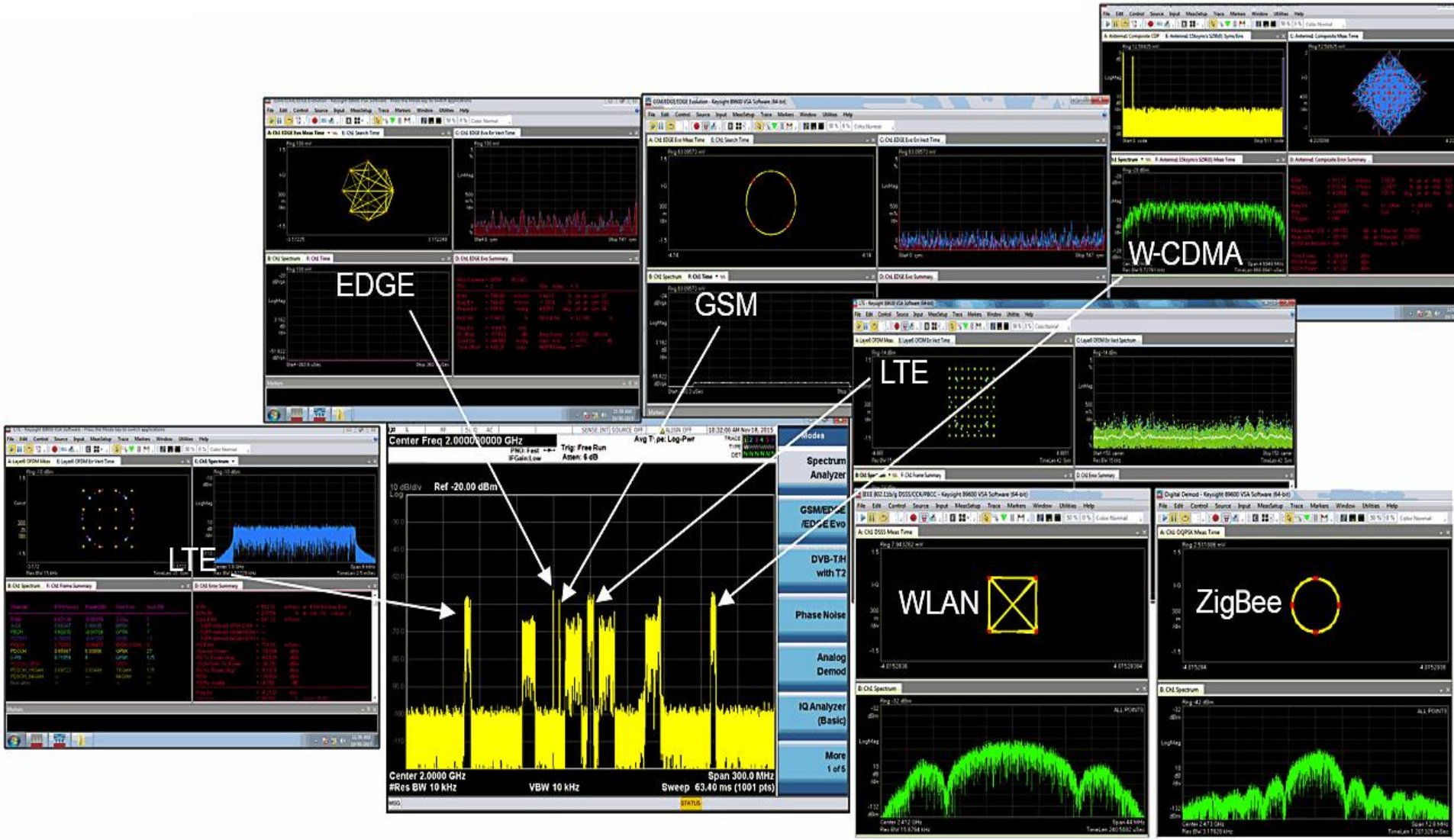
Measurement result for carrier (C6) of 8 multi-carries Demod (CF:28.15GHz) *removed C5, C7 without* Signal Optimizer



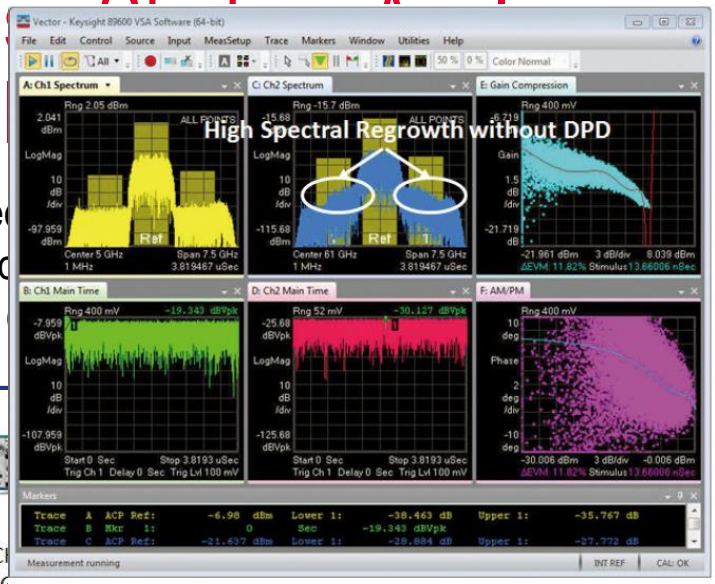
Case Study – Examining 5G candidate waveform coexistence with 3G, 4G, and PAN waveforms (< 6 GHz)



KEYSIGHT TECHNOLOGIES

Ca… Mil…

The testbe… …on
amplifiers … …agram
shows the …



PA Output- No DPD

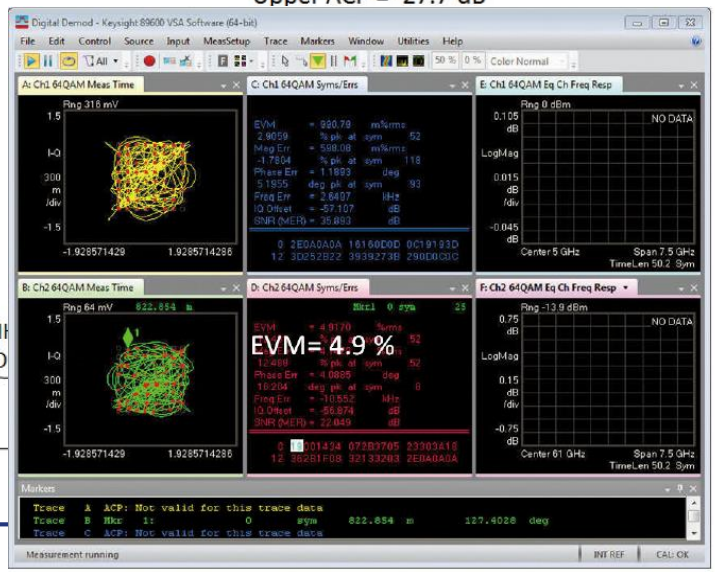
Lower ACP = -28.8 dB

Upper ACP = -27.7 dB

PA Output- With DPD

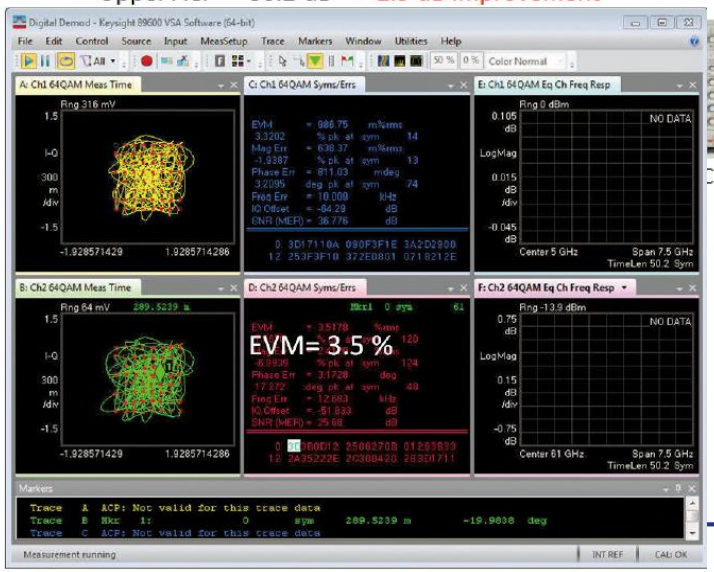
Lower ACP = -32.9 dB => 4.1 dB improvement

Upper ACP = -30.2 dB => 2.5 dB improvement



PA Output- No DPD

EVM = 4.9 %



PA Output- With DPD

EVM = 3.5 % => 1.4% improvement

www.keysight.com/find/5G-insight

무선통신 기술 자료로 "5G 설계 및 테스트 시간을 단축 하세요"

차세대 5G 통신에 필요한 새로운 자료:

- ***새로운*** 포스터: "방대한 MIMO에 대해 알아야 할 10가지 사항"
- ***새로운*** "5G용 방대한 MIMO 구현 및 테스트의 과제 검토" 어플리케이션 노트
- "통신 시스템 아키텍트를 위한 5G 물리 계층 모델링 가이드" 백서
- "5G Air 인터페이스의 특성 분석을 위한 채널 사운딩 측정 시스템 정의" 어플리케이션 노트
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- 5G 자습서 "방대한 MIMO 기술 통찰력과 과제"
- 5G 자습서 "5G용 밀리미터파 액티브 컴포넌트 특성 분석"
- 5G 자습서 "Error Vector Magnitude Measurements Fit for 5G"
- 5G 자습서 "5G의 꿈을 현실로"

Thank you!