

Using MATLAB to develop 5G RF Front End components and their control algorithms

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QUALCOMM (UK) Limited



3rd October 2018



Qualcomm

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Fabless semiconductor company

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In 3G/4G LTE modem

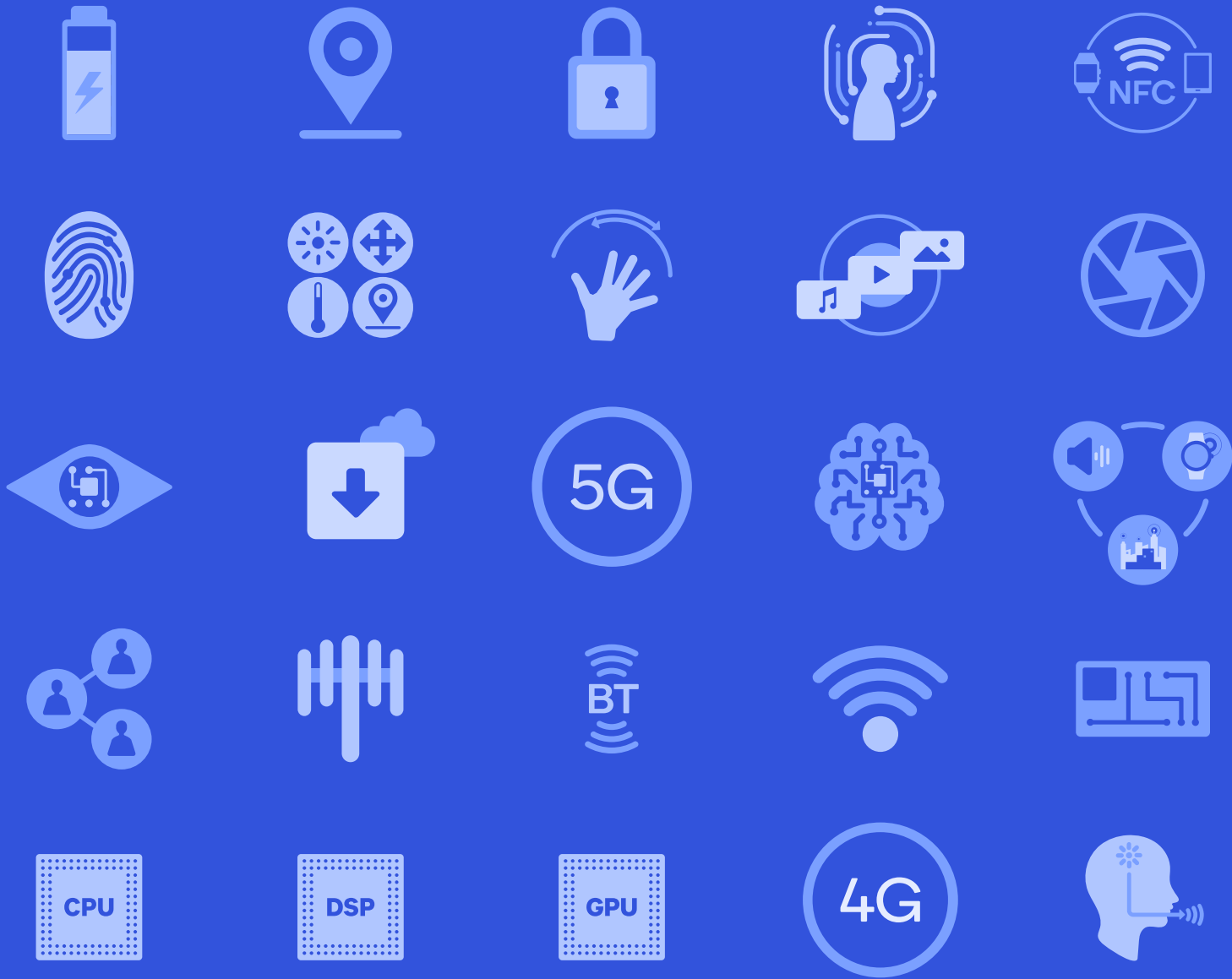
30+

Years of driving the evolution of wireless

804M

MSM™ chipsets shipped FY '17

Sources: Qualcomm Incorporated data, as of Q4 FY17; IHS, May '18; MSM is a product of Qualcomm Technologies, Inc. and/or its subsidiaries



From the
smartphone to 5G,
it all starts
with Qualcomm

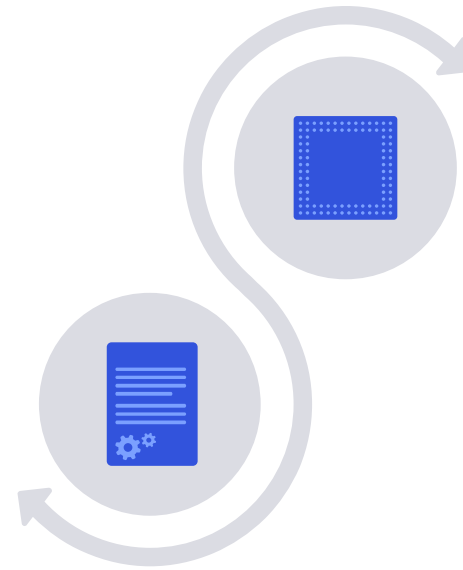
\$53+ billion cumulative
investment in R&D

5G Development Process



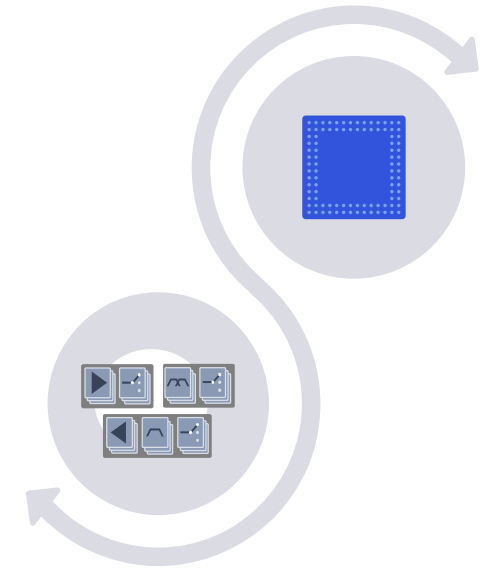
Simulate

Build simulations that prove that the impossible is achievable



Design

Design the RF and Analogue hardware.
Design the control algorithms

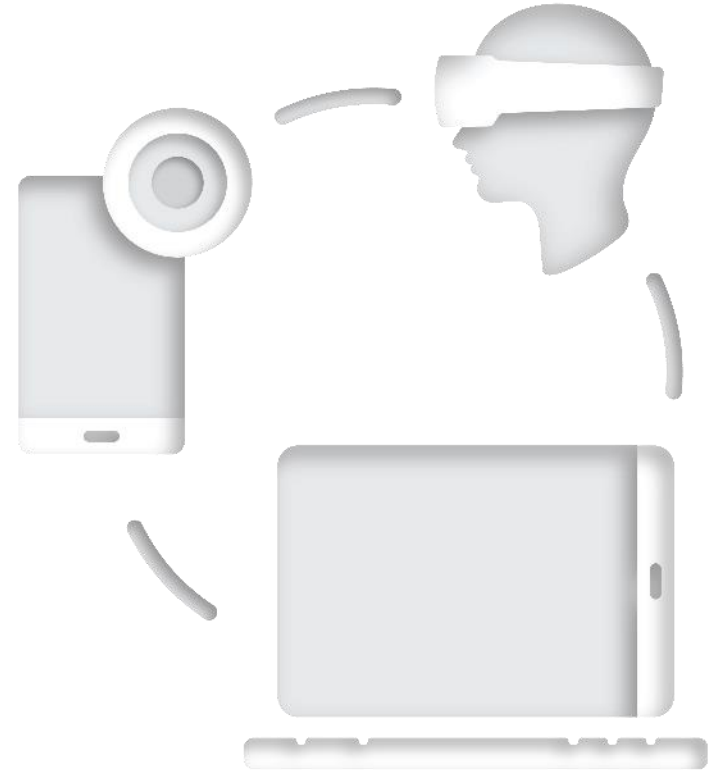


Validate

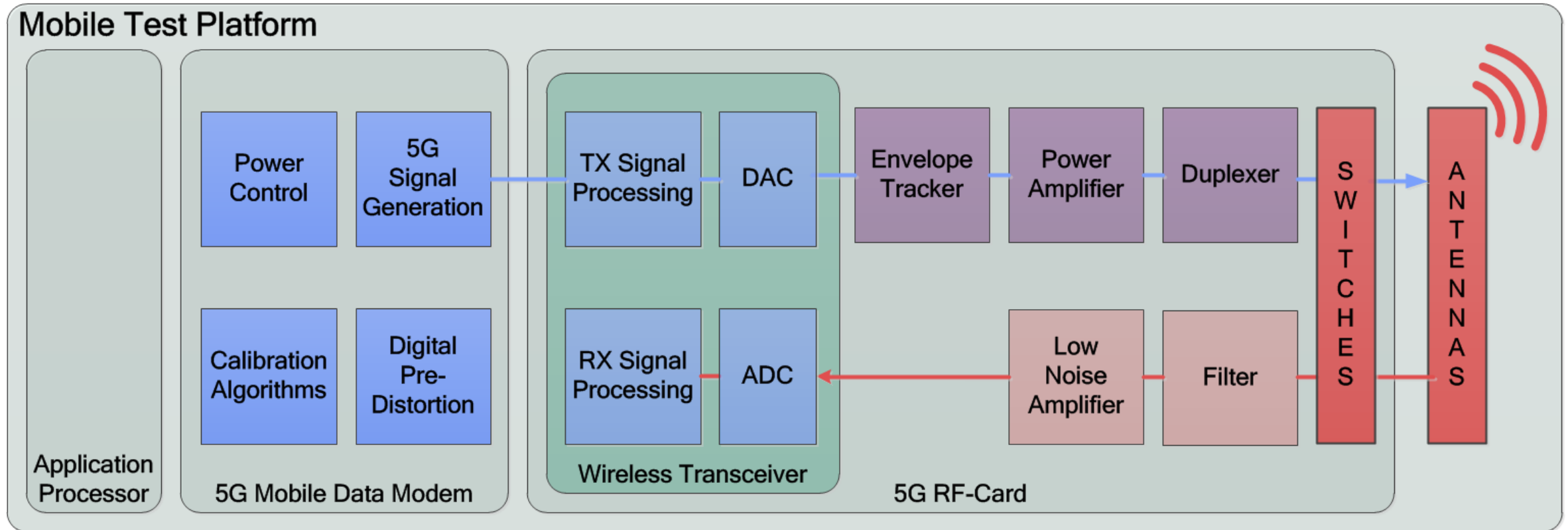
Validate that the system meets the design requirements, at component, sub-system and phone levels.

5G Mobile

RF Front End - Simulation



5G Target Hardware

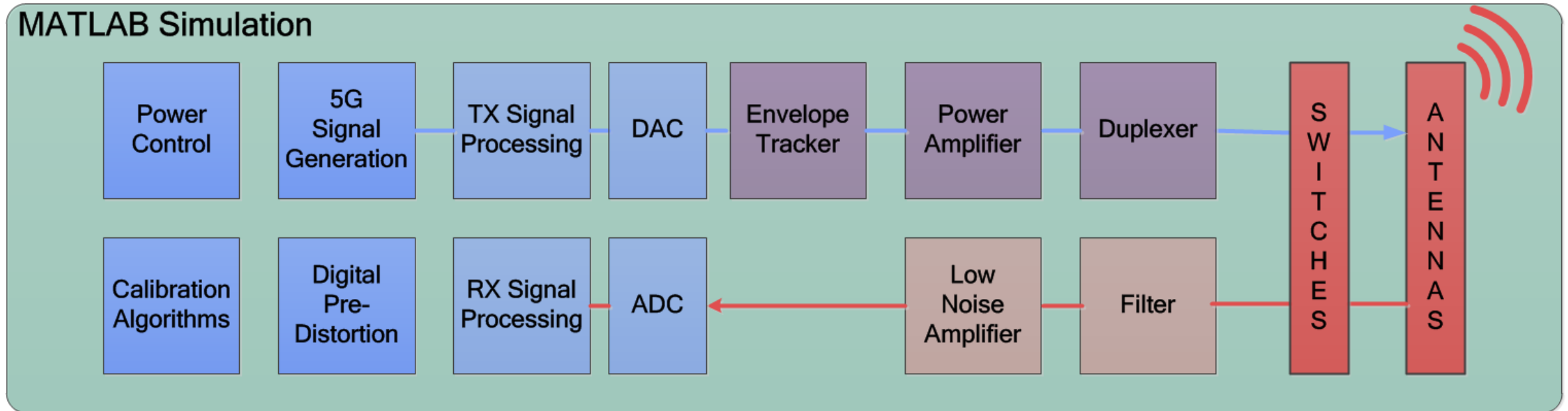


The target hardware is a fully function phone including 5G Mobile Data Modem and 5G RF-Card

The RF Front End supports over 30* different RF bands using multiple Power Amplifiers and Envelope Trackers

(*) The number of bands supported is chosen by the phone manufacturer

Simulation: Building the MATLAB System Model



MATLAB is used to build a complete model of the TX and RX paths

The digital blocks are modelled in a bit accurate manner

We include accurate Power Amplifier models based on bench measurements

Simulation: Predictions

Predicted System Parameters:

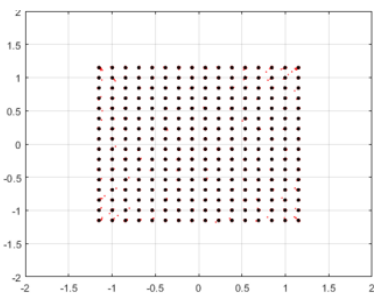
- Error Vector Magnitude
- Adjacent Carrier Leakage Ratio
- System Efficiency
- RX Band Noise

System Parameters that are optimized:

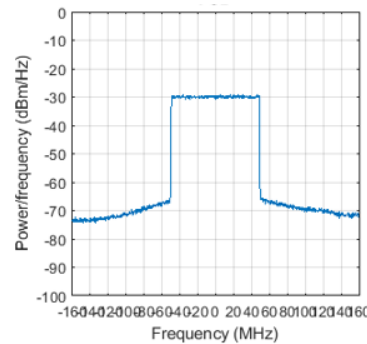
- PA Output Power
- Analogue Architectures
- Digital Settings
- DPD Settings

System Parameters that are swept:

- Operating Band and Channel
- Channel Bandwidth
- Number of Resource Blocks
- Modulation Schemes
- Time Slot Allocation
- PA Output Power



Error Vector Magnitude



Power Signal Density

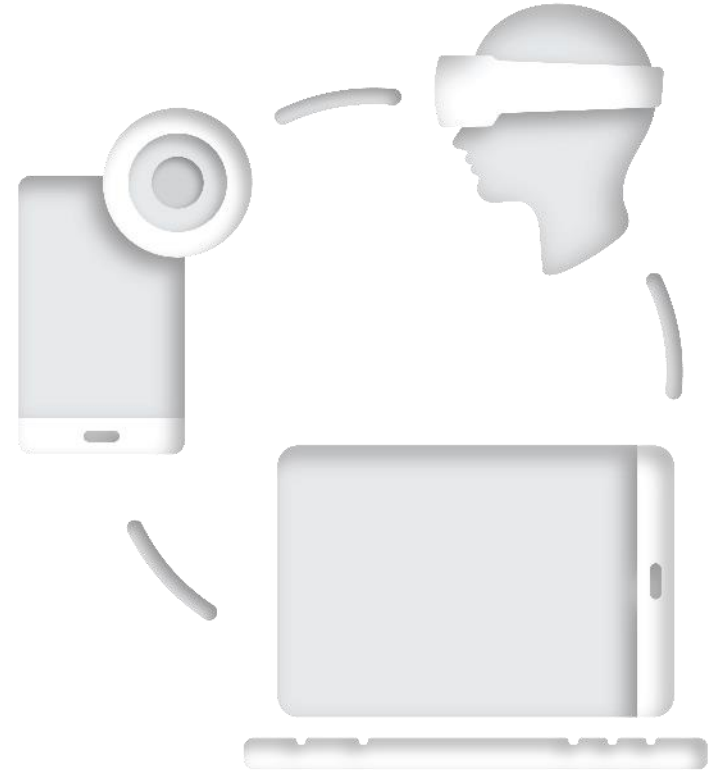
At each test point the key system parameters can be predicted

Design parameters are optimized to balance performance against efficiency

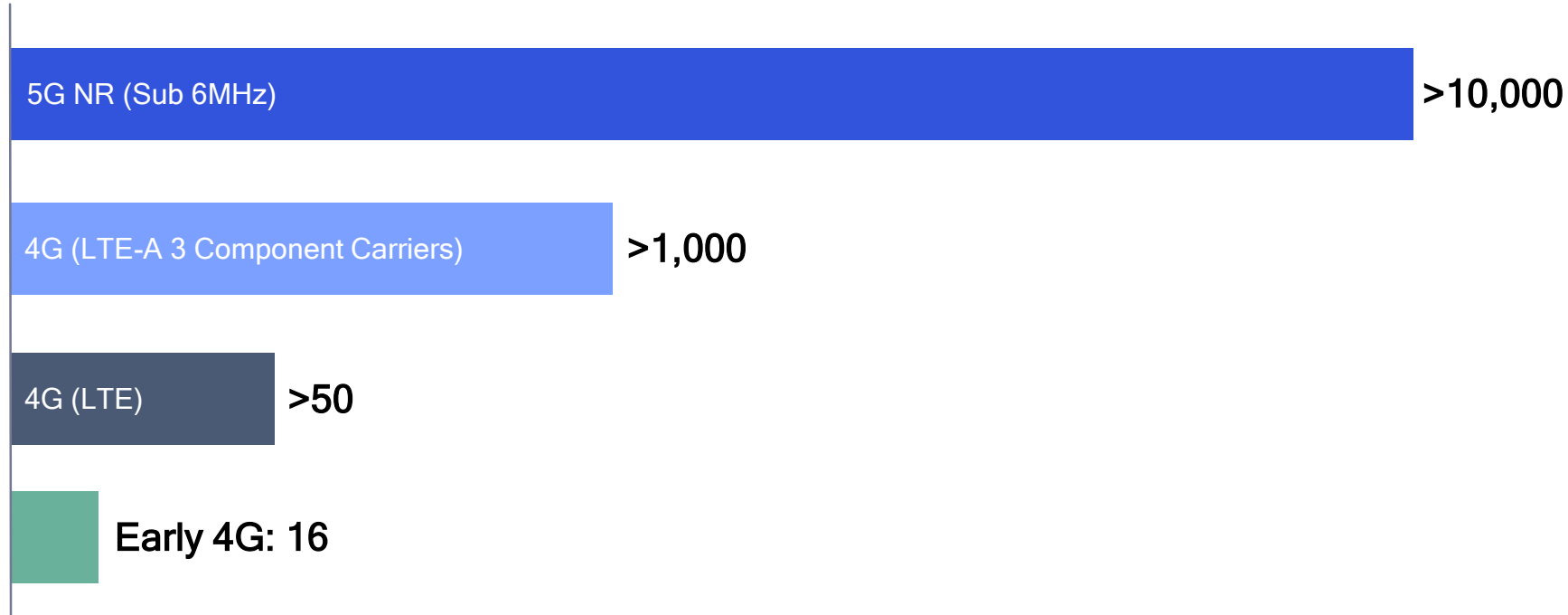
Predictions are repeated for different waveform types, to make sure we have a full solution

5G Mobile

RF Front End - Validation



Validation Challenges: Number of Waveform Combinations



Waveform Combinations by Technology [Not to scale]

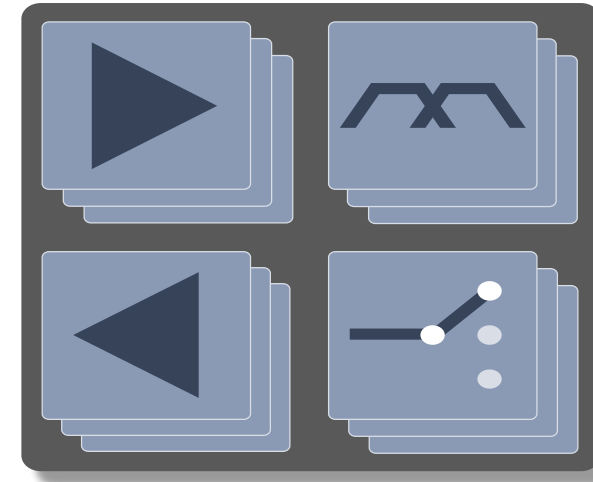
The number of possible Waveform Combinations is increasing exponentially with each new standard

Channel Bandwidths:	x10
Modulation Schemes:	x5
Active Resource Blocks:	1 to 273
Time Slots per Sub-Frame:	x8 (UL or DL)
Frequency Division Multiplexer:	x2
Sub-Carrier Spacing:	x3

Validation Challenges: Number of Supported RF Bands

Number of Supported RF Bands:

- 1990 2
- 2000 5*
- 2010 10*
- 2018 20*



PA module incl. duplexer
(PAMiD)

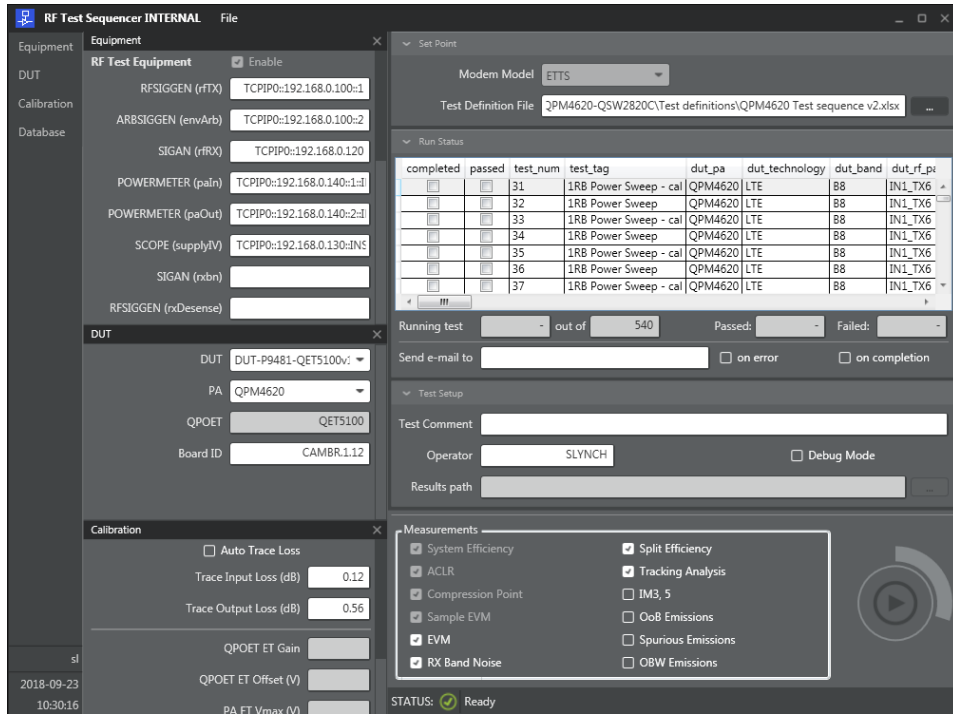
Mobile phones are being used in more bands around the world.

Each band is powered by a different Power Amplifier chain.

LTE-A: 48 bands
5G NR: 26 bands
- 5G is being targeted at some LTE bands

(*) The number of bands supported is chosen by the phone manufacturer

Validation Tools: Automated Test Sequencer



test_num	dut_technology	dut_band	dut_rf_path	dut_rf_mode	dut_tracking_mode	dut_gain_state	dut_port	tx_frequency_mhz	tx_waveform	tx_waveform_filename	tx_waveform_id	detrnght_function	detrnght_parameter	detrnght_filename	xpt_cal_vdd_min_v	xpt_cal_vdd_max_v	vdd_min_v	vdd_max_v	vdd_rpt_v	puu_rhott_v	puu_vdd_v	puu_vdd_min_v	puu_vdd_max_v	power_cal_mode	set_point_type	set_compression_point_db	point_dbm	pin_dbm	rebgp_scale_backoff_db	delay_mode	delay_method	delay_manual_us	delay_wsc_12h	dpl_mode	dpl_method	dpl_wsc_12h	etec_mode	lout_impedance_ohm	lbe_detrnght_function	lbe_detrnght_order	lsc_detrnght_low_vmin	lsc_detrnght_low_vmax	lsc_detrnght_high_vmin	lsc_detrnght_high_vmax	temperature_djgc	usd1	addr1	data1
1	LTE	B12	INI_TX7	5M	ET	GO	707.5	0	1R80	exponential	1	5.5	1.5	3.8	1.8	calibration	vmax-cpoint	3	0	calibration	firmware	0	calibration	bas	0	0	22																					
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A test sequencer controls the DUT and test equipment. The same application is used to control all platforms.

Test definitions are created using Excel files containing 2,000+ tests per Power Amplifier module

We have over 50 test parameters that can be swept during a test sweep. From waveform to temperature.

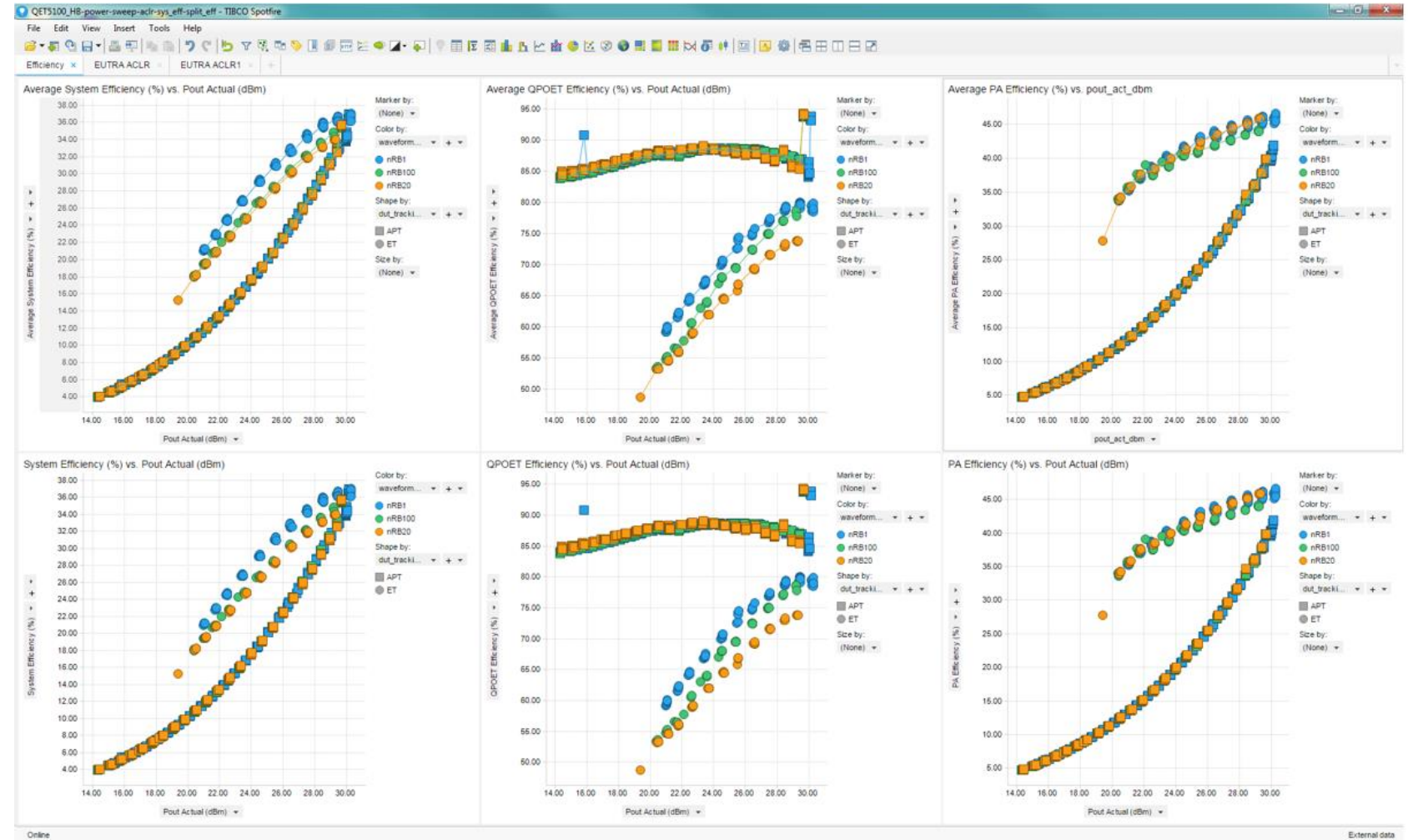
Validation Tools: Data Visualization

Validation Tools

We also store test parameters and detailed results in a MySQL database.

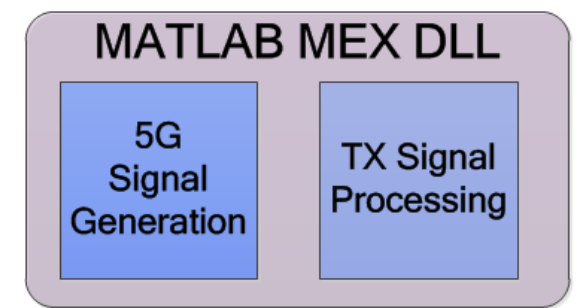
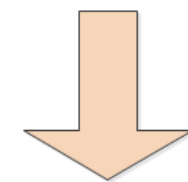
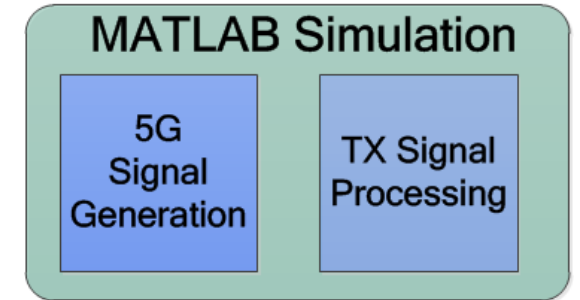
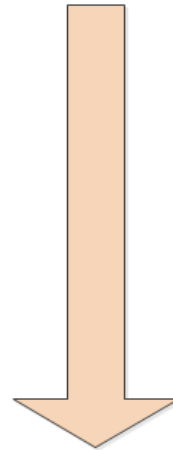
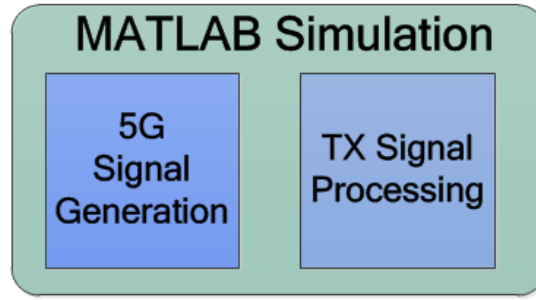
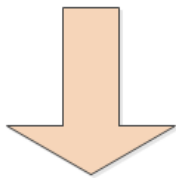
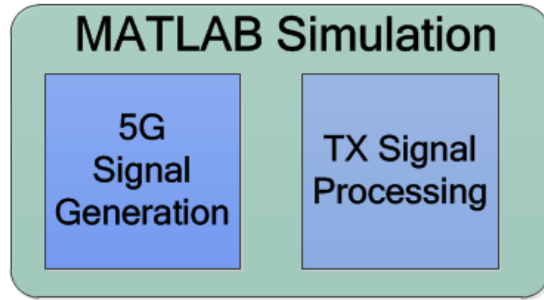
Detailed reports are extracted using a 3rd party report generator.

This approach makes comparing device models and variants a lot easier.



Database Extracted Report

Validation Tools: Waveform Generation



Phase#1

Generated waveform files using the MATLAB system simulation.

At 250 LTE waveforms the release image was too large for our release system.

Phase#2

Integrated simulation into the test software. Could not be shipped to customers as the IP was too sensitive.

Phase#3

Used MATLAB Coder to create a MEX DLL, which allowed the sensitive IP to be released externally.

Waveform Generation: MATLAB CODER Challenges

- Code was not designed for code generation
 - Needed to rewrite some sections that used cells (*MATLAB R2017b and later supports cells*)
- Large number of files involved; over 400 files per Modem model
- The code generation process is complicated having multiple phases:
 - Review, Compile, Execute
- Specific versions of MATLAB need to be used, due to MEX API changes
- Needed to pass open source code scanning before external release.

Our first pass at generating a waveform library took several months

We can only ship binaries where the source code has been scanned for 3rd party code.

Waveform Generation: MATLAB CODER Advantages

- Building a library has the following advantages:
 - Dependences on MATLAB toolboxes are reduced
 - But this may affect performance (FFT*)
 - Replaces 400+ files with a single file:
 - Allows different waveform generation libraries to be used in parallel in an application
 - Enables secure IP delivery, both internally and externally.
 - Using waveform generation libraries removes the need to ship waveforms
 - Reduces build copy times from 2hrs to 15mins

Building a MEX library enables native MATLAB functions to be called.

Building a Windows DLL enables other technologies to use the IP block

Waveform Generation: MATLAB CODER Successes

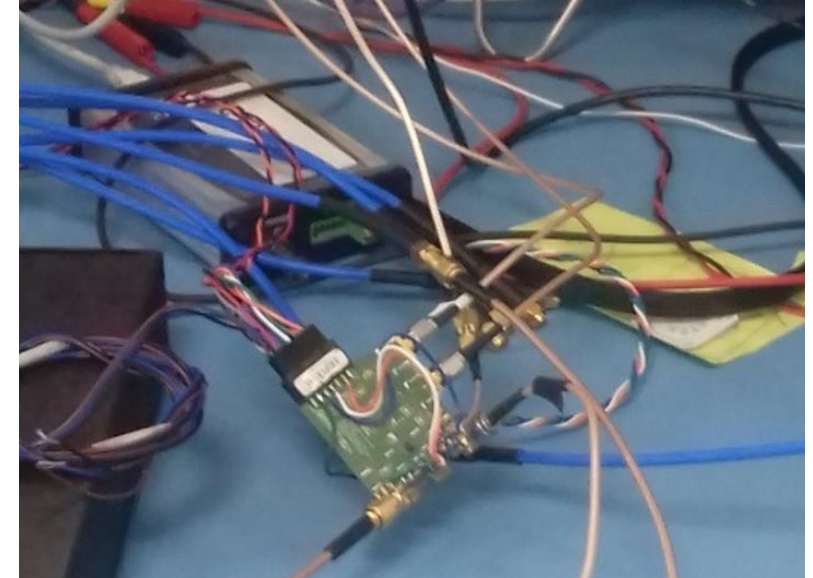
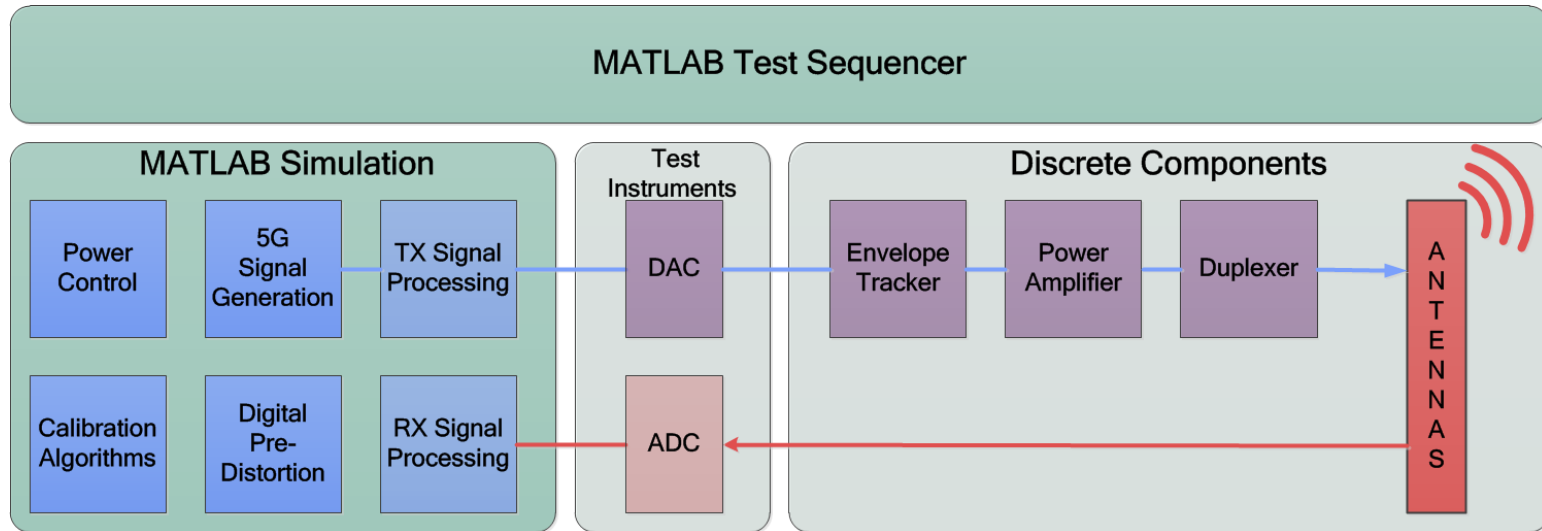
- We have now generated Modem waveform libraries for the following 3GPP standards:
 - LTE
 - LTE Advanced
 - LTE TDD Advanced
 - 5G NR

These libraries are fully integrated into our range of RF test applications.

Building the 5G NR library took a few weeks, and can be rebuilt in hours as the standard matures.

We have also released waveform generation tools for IC simulation and Product Test departments.

Validation Tools: Discrete Component Testing

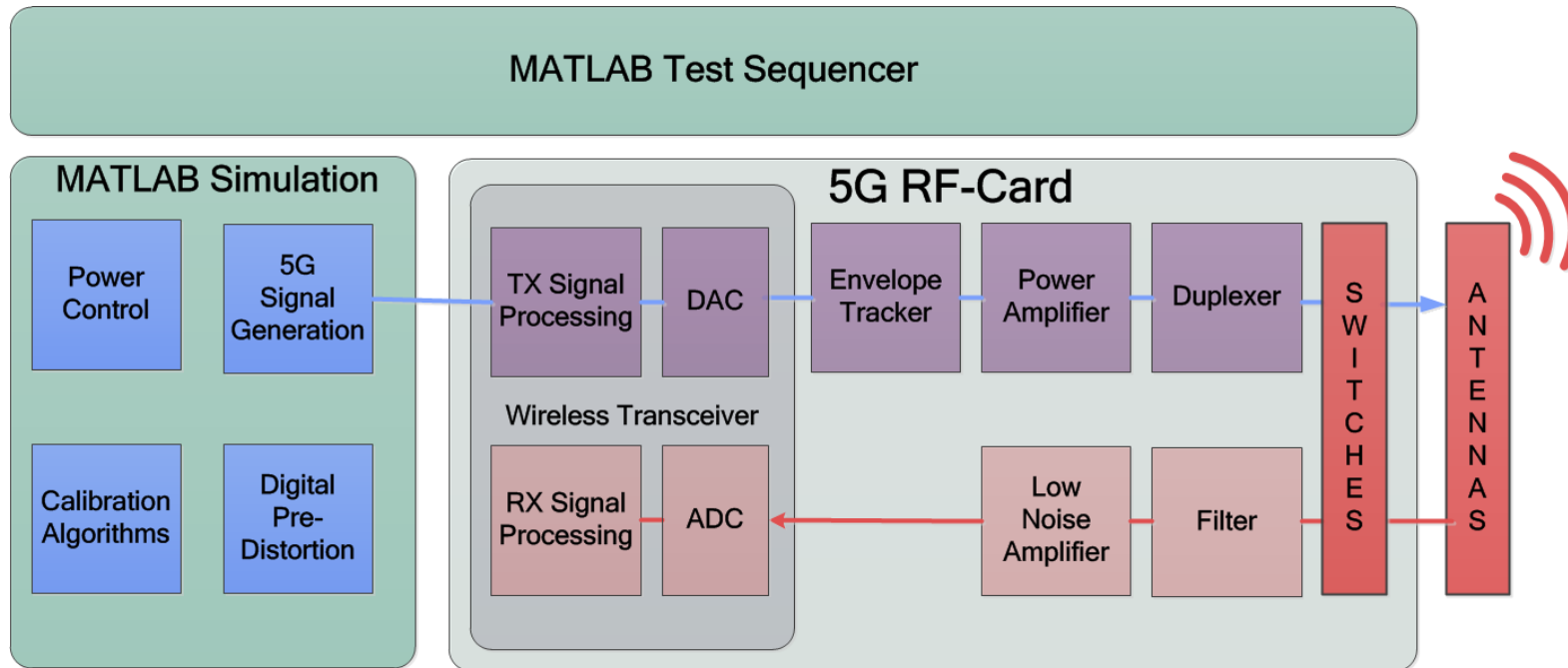


Most of the MATLAB System Model is used to calibrate the system and generate pre-distorted test signals

Third party test equipment is used to generate and capture the 5G RF signals.

The PA and RF Systems groups use this system to validate components and algorithms

Validation Tools: RF-Card Testing with Wireless Transceiver



The MATLAB System Model is used to calibrate the system and generate pre-distorted test signals

Settings from the MATLAB System model are used to program the Wireless Transceiver

The IPS group uses this platform to validate RF-Cards. The systems group use it for algorithm development

Validation Challenges: Multiple Test Platform Support



VST2.0

National Instruments:
RF TX and RF TX are integrated
into one card.



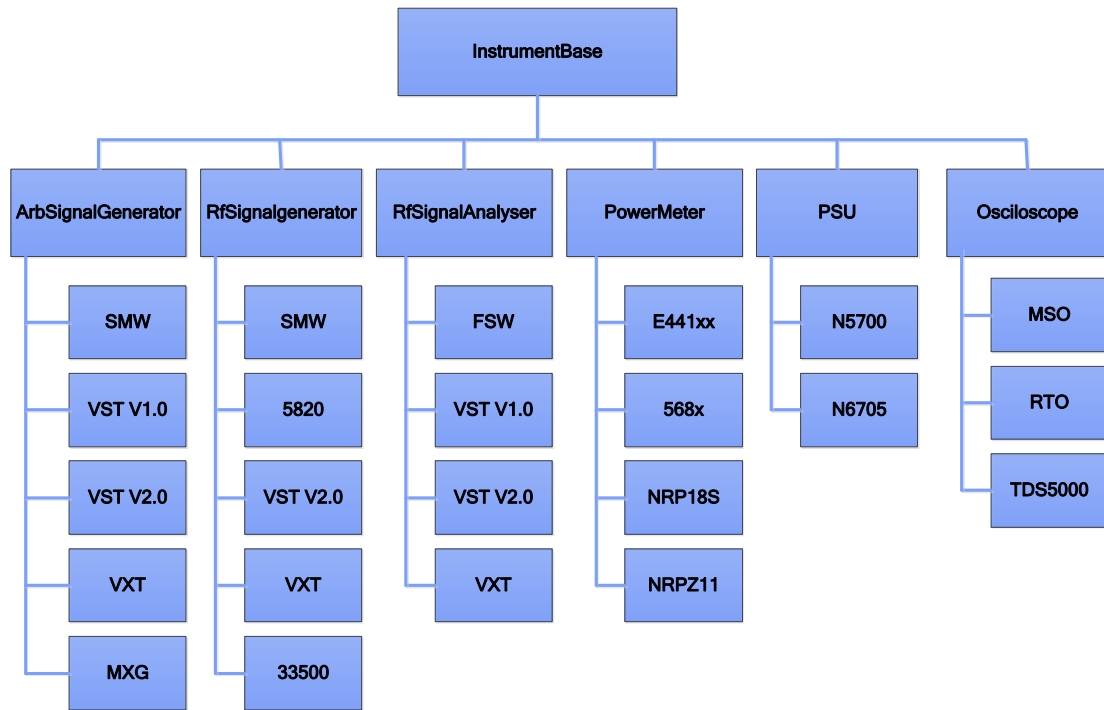
SMW 2000A



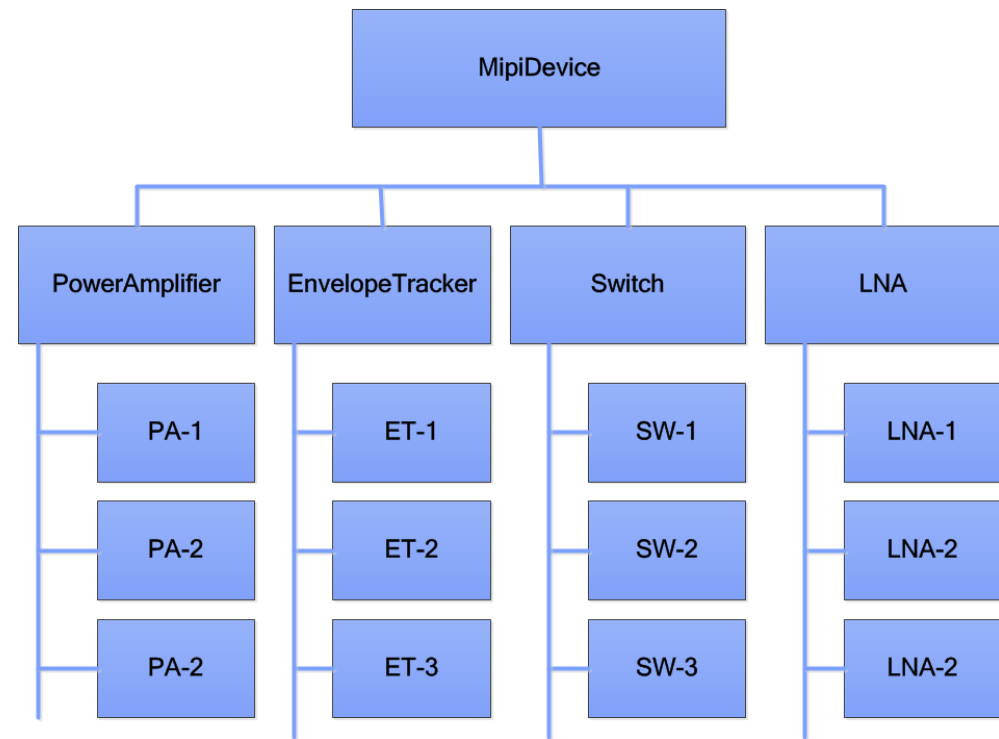
FSW

Rohde & Schwarz:
RF TX and Envelope TX
are in the SMW. RF RX is
in the FSW.

Scalability: Using MATLAB OO



Instrument Class Diagram



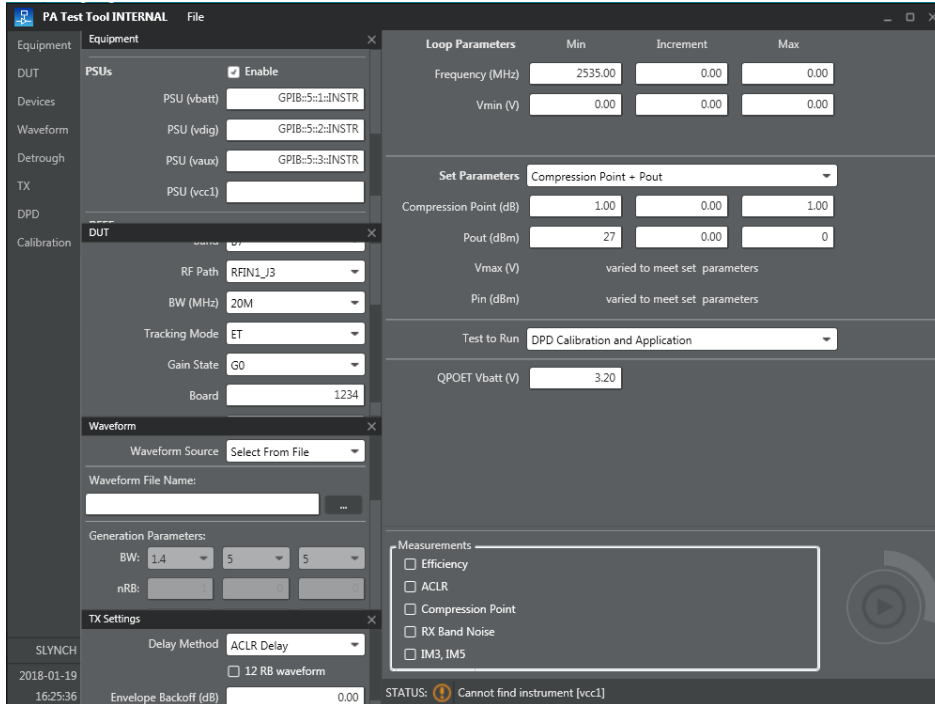
MIPI Device Class Diagram

We use abstraction to support many different types of test equipment, and DUT variants.

DUTs may contain any combination of: Envelope Tracker, Power Amplifier, RF Switches, Low Noise Amplifiers

Validation Challenges: Code Testing

User Interface Testing



Device Driver Testing



One GUI has over 50 different operating modes.
Using MATLAB OO we are able to programmatically control and verify correct GUI operation.

Using a class based on matlab.mixin.SetGet we can replace the Instrument Control VISA object. Thus allowing unit testing of instrument drivers




Summary

Qualcomm 5G built using MATLAB

- MATLAB has enabled Qualcomm Technologies, Inc. to fully model the RF Transceiver and key analogue and RF components.
- The MATLAB models are then used to optimize and verify the RF Front End through all phases of its development.
- The MATLAB Coder product has allowed us to release sensitive IP both internally and externally in a secure manner.
- MATLAB's OO features have enabled a scalable and maintainable set of tests solution to be created by a small team.



Thank you!

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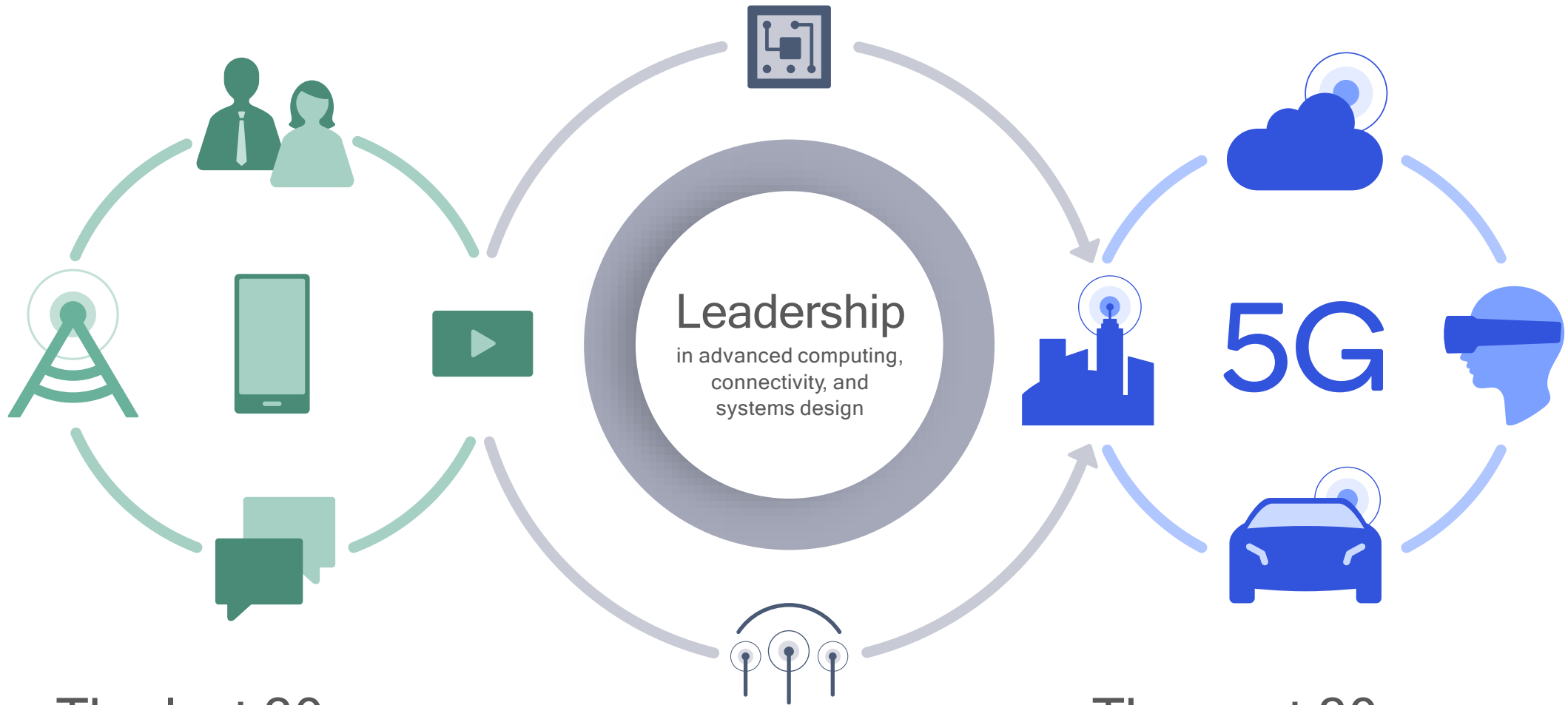
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Inventing the 5G foundation



Invention for what's next

in the increasingly smart and connected world



The last 30 years
Interconnecting people

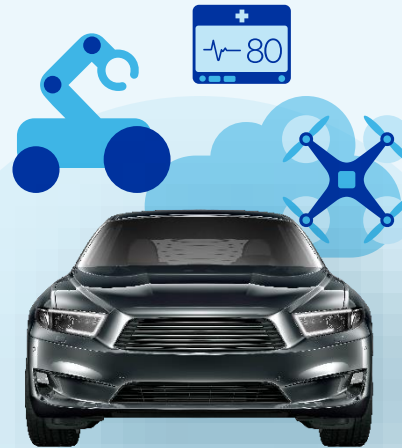
The next 30 years
Interconnecting their worlds

Our vision for 5G is a unifying connectivity fabric

- Delivering always-available, secure cloud access



Enhanced mobile
broadband



Mission-critical
services

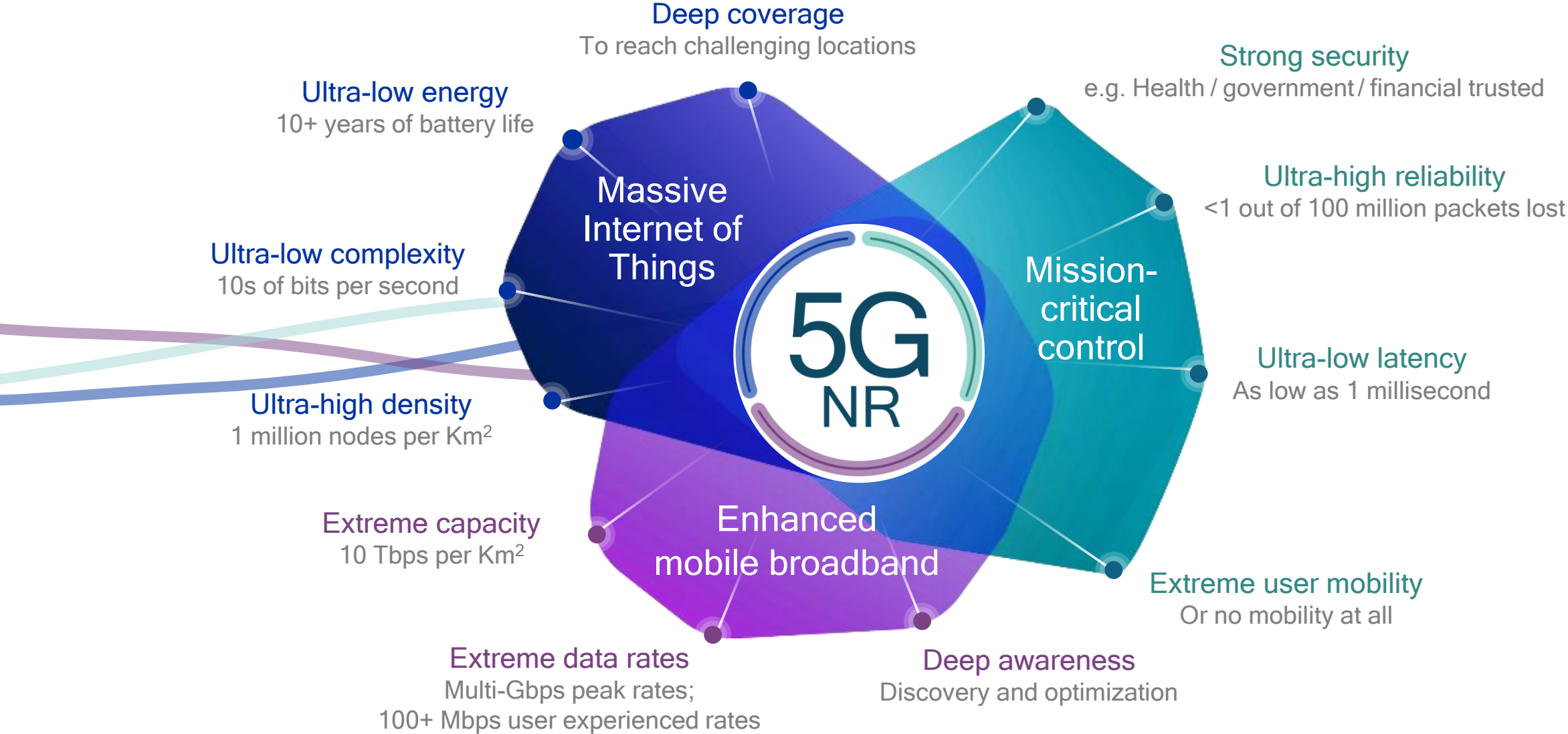


Massive Internet
of Things

Unifying connectivity platform for future innovation

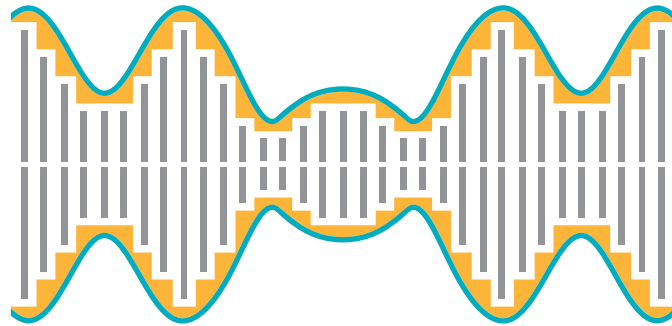
Convergence of spectrum types/bands, diverse services, and deployments

Scalability to address diverse service and devices

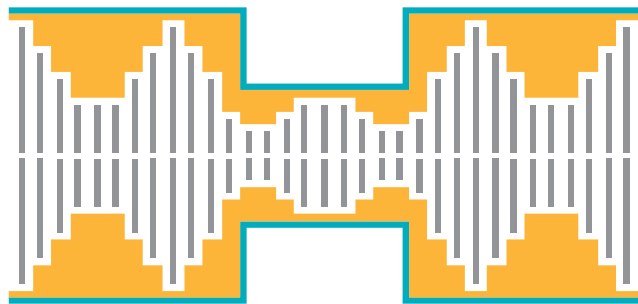


Envelope Tracking Performance

Envelope Tracking (ET)



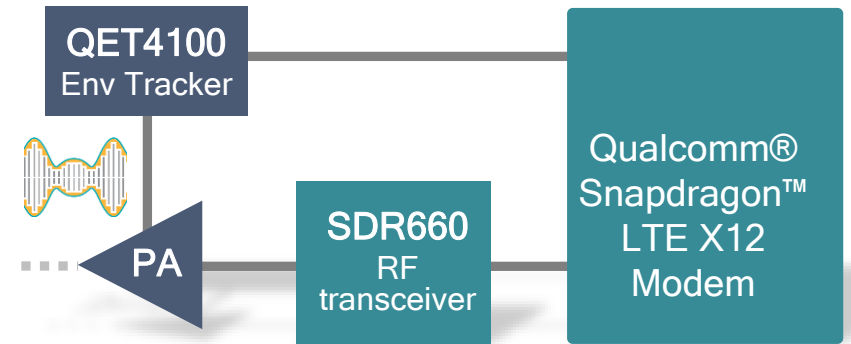
LTE waveform and envelope



Average Power Tracking (APT)

■ = Wasted energy

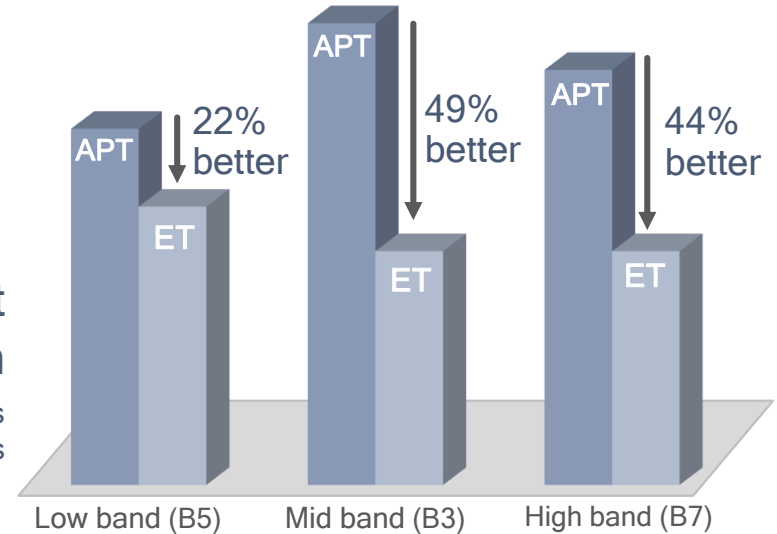
Up to 30% higher power efficiency compared to APT



Current consumption

Source: Lab measurements on commercial devices

@22 dBm Pout at antenna



Envelope Tracking eliminates wasted PA power for LTE and 5G waveforms

Current consumption and thus battery life is a key performance indicators, especially for high end devices