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

By: Sean Lynch
Senior Staff Engineer
QUALCOMM (UK) Limited

3rd October 2018
Fabless semiconductor company

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

Source: Qualcomm data, as of Q3 FY18
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
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.

Toolbox’s used: Signal Processing, DSP System, Communications System
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

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

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

Waveform Combinations by Technology [Not to scale]

- 5G NR (Sub 6MHz): >10,000
- 4G (LTE-A 3 Component Carriers): >1,000
- 4G (LTE): >50
- Early 4G: 16

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Supported RF Bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>2</td>
</tr>
<tr>
<td>2000</td>
<td>5*</td>
</tr>
<tr>
<td>2010</td>
<td>10*</td>
</tr>
<tr>
<td>2018</td>
<td>20*</td>
</tr>
</tbody>
</table>

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

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

LTE-A: 48 bands
5G NR: 26 bands
- 5G is being targeted at some LTE bands
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.
We record test parameters and RF measurement results using Excel. This is useful for smaller test runs, but parsing 1,000 Excel sheets is tedious for longer runs.
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.
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

(*) Third party FFT libraries are available to license on a commercial basis

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.
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

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

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

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

Device Driver Testing

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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Inventing the 5G foundation
Invention for what’s next
in the increasingly smart and connected world

Leadership
in advanced computing, connectivity, and systems design

The last 30 years
Interconnecting people

5G

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

Based on target requirements for the envisioned 5G use cases

**Ultra-low energy**
- 10+ years of battery life

**Ultra-low complexity**
- 10s of bits per second

**Ultra-high density**
- 1 million nodes per Km²

**Extreme capacity**
- 10 Tbps per Km²

**Extreme data rates**
- Multi-Gbps peak rates; 100+ Mbps user experienced rates

**Deep coverage**
- To reach challenging locations

**Enhanced mobile broadband**

**Mission-critical control**

**Deep awareness**
- Discovery and optimization

**Strong security**
- e.g. Health / government / financial trusted

**Ultra-high reliability**
- <1 out of 100 million packets lost

**Ultra-low latency**
- As low as 1 millisecond

**Extreme user mobility**
- Or no mobility at all
Envelope Tracking Performance

Envelope Tracking (ET) eliminates wasted PA power for LTE and 5G waveforms.

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

Enveloped Tracking (ET) vs. Average Power Tracking (APT)
- Up to 30% higher power efficiency compared to APT

Source: Lab measurements on commercial devices

- @22 dBm Pout at antenna

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