



Design, Analysis and Verification of 5G NR Waveforms using MATLAB

Lekha Wireless Solutions

- Introduction
- Brief Introduction to 5G
- 5G @Lekha
- Design and Verification Approach
- MATLAB Based Analysis & Results
- Demo
- Summary and Conclusions

Waveforms
IPs
Reference Solutions
Product Solutions
Engineering Services

- Started in 2010, Reaching 9 years of Success
- Focussed on Wireless Infrastructure Products, IPs & Services
- Engineering Team of 120+ with average experience of 7+ years
- Engineering Expertise across all Wireless Domain Verticals of SW and HW driving Research, Design & Development and Manufacturing
- Ranked among fast 50 Growing Technology company in India by Deloitte for year 2014 and 2013
- Successful launch and deployment of **WaveGuru SDR**, **Laksha**, **WaveDyut** and **Vyapi** Radio Products for Industrial IOT, Private Networks and Tactical Communications
- IP and Reference Solutions for 4G and 5G
 - **LTE eNB, LTE UE, NB-IoT UE and 5G NR gNB**
- **IDEX (Ministry of Defence, Govt of India) Winner, 2019**

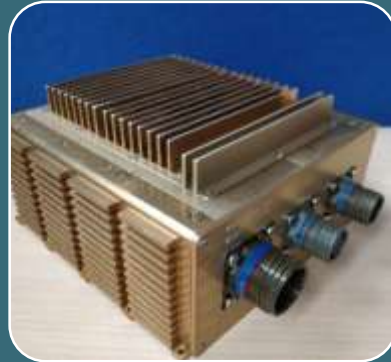
Solutions – Defence Networks

Solutions – Commercial Private Networks



Laksha

- DSSS, SOQPSK and Single Carrier Waveforms
- Telemetry PTP Links
- Low Latency, High Reliable Links
- Customers: Missile & Satellite Networks



WaveDyut

- COFDM Waveforms
- High Throughput PTP, PTMP Links
- Customers: UGV, UAV Networks
Wireless Backhaul Solutions



Vyapi

- 3GPP OFDM, SC-FDMA Waveform
- 10W Macro eNB
- 2W Small Cell NIB
- Outdoor Vehicle Mount UE
- Customers: Tactical Networks
Private Networks



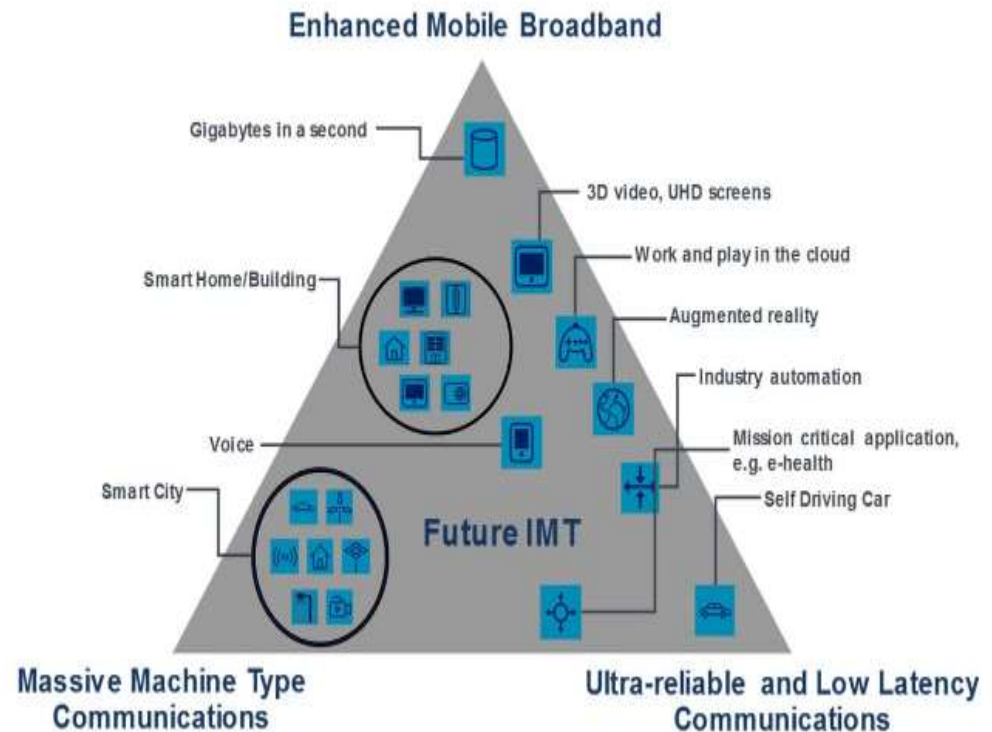
5G IP

- 5G NR eMBB Waveforms
- 100 MHz, 200 MHz BW
- Massive MIMO
- NB-IOT
- Reference Solutions

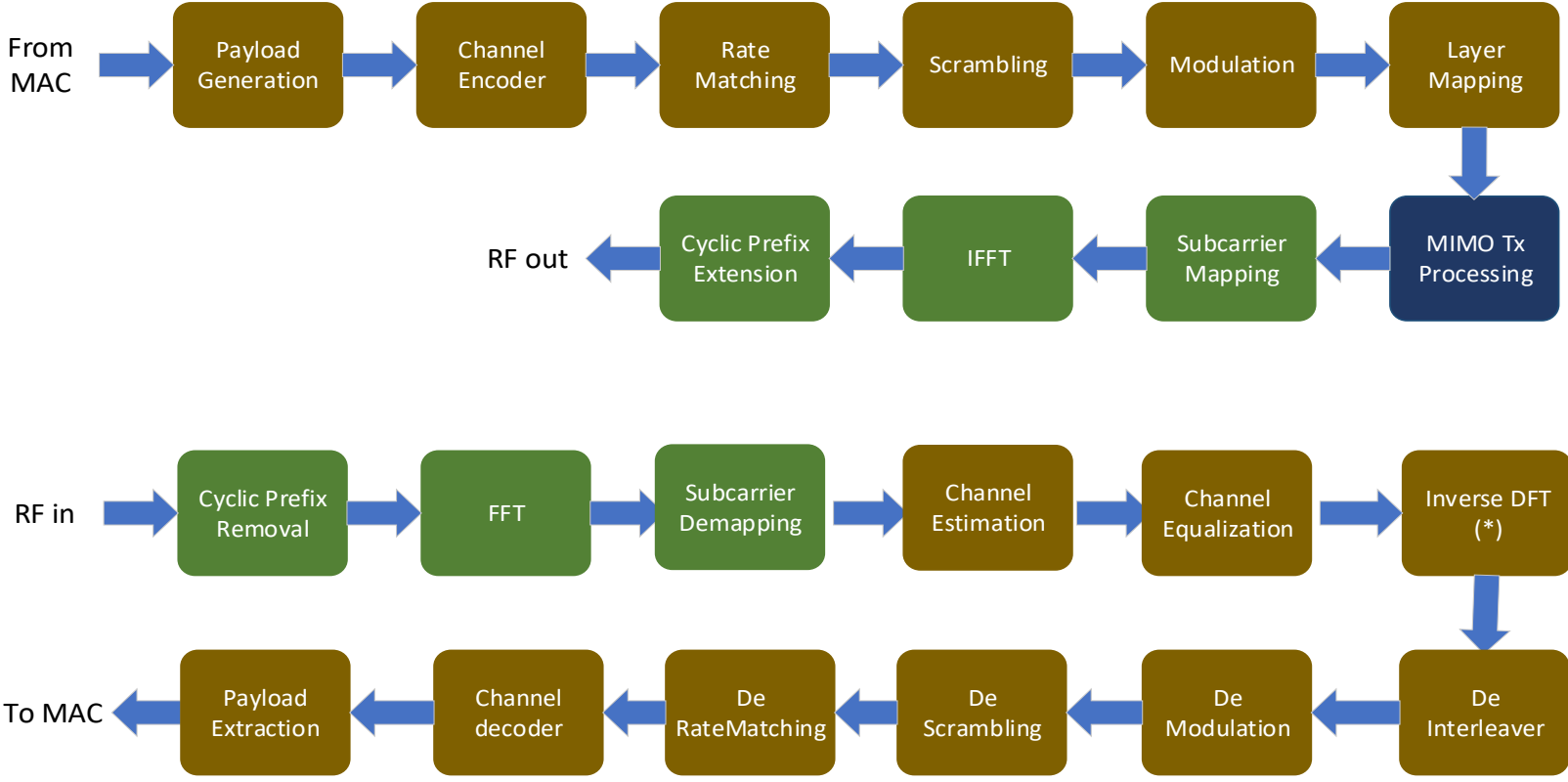
Brief Intro to 5G – Highlights

- 5G NR 3gpp in Release 15 and Release 16
- 5G Tiers include eMBB mMTC and URLLC
- eMBB for High throughputs
- mMTC provides machine to machine communications and IOT applications
- URLLC end to end latency ~1ms
- 5G cloud architecture, network slices enabling low CAPEX and OPEX costs

5G Usage scenarios



Brief Intro to 5G – Signal Chain



Per User
Per Antenna
User to RF crossover

(*) Optional Block

5G Work @Lekha: Small Cell gNB IP



Sl. No.	Parameter	Description
1	3GPP Standard Specification	Release 15 (FR1)
2	Channels supported	SS Block (PSS,SSS,PBCH) DL Control Channel (PDCCH) DL Shared Channel (PDSCH) Random Access Channel (PRACH) UL Control Channel (PUCCH) UL Shared Channel (PUSCH)
3	Sub Carrier Spacing	15kHz, 30kHz, 60kHz
4	Bandwidth	Upto 100MHz (FR1)
5	Modulation Scheme	QPSK, QAM16, QAM64, QAM256
6	Number of Antenna	4T 4R
7	Number of Layers	DL 4 Layers / UL 2 Layers
8	Duplexing Mode	FDD,TDD
9	System Throughput	Upto 2.4Gbps

Design & Verification Approach



SN	Description	Test Objective
1	Module Level Functional Validation	Ensures the Developer to deliver for Integration phase
2	Module Level Performance Validation & Design Improvements	
3	Integration Level Signal Chain Validation	Ensures the Developer to deliver for End to End System Test
4	3GPP 38.141-1 Conducted Conformance Testing	Stack Conformance Test for Product Integration

GUI → PHY Configuration

5G NR and LTE Test Solutions

127.0.0.1:8000/fgnr/gnbtbx/

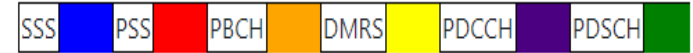
Lekha 5G NR LTE Device Settings

System Settings Phy Settings Frame Settings

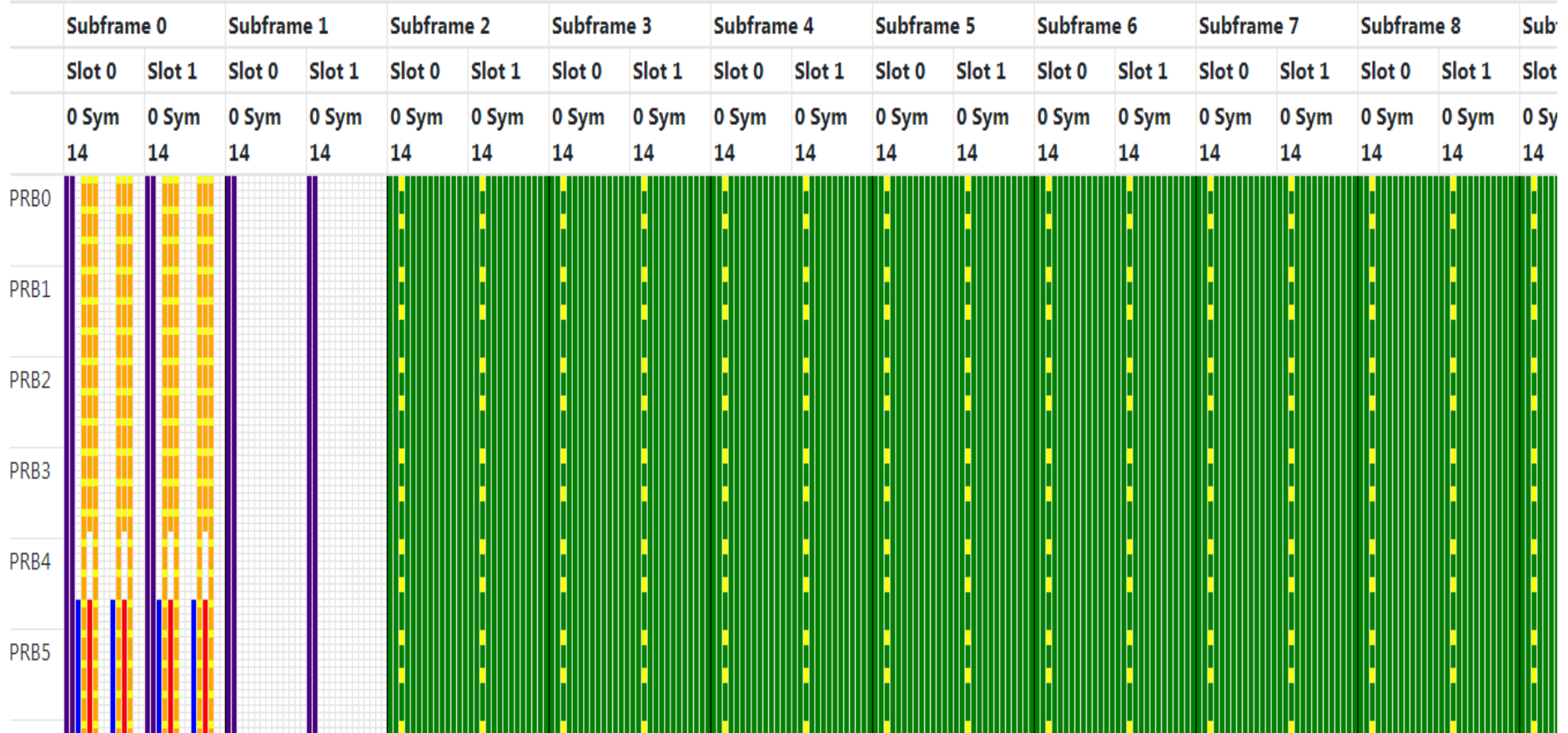
Frequency Band	fr1	Operation Band	nr1
ARFCN	422000	Frequency(MHz)	2110
Bandwidth(MHz)	5	SCS(KHz)	15
Numerology	0	Sampling Rate(KHz)	7680

Next View Frame Generate

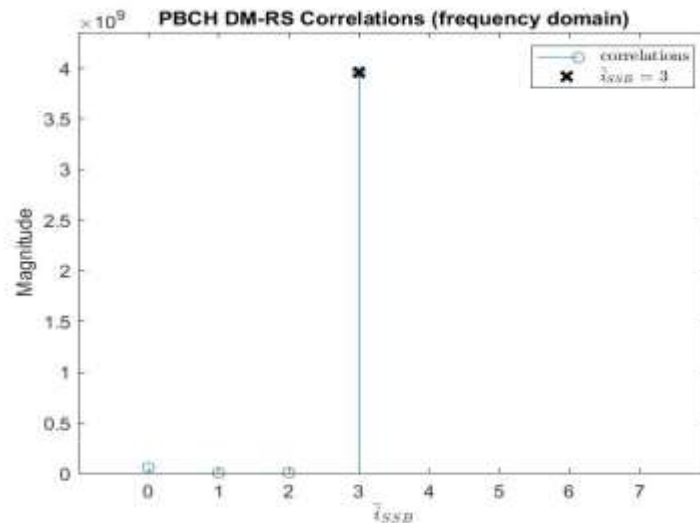
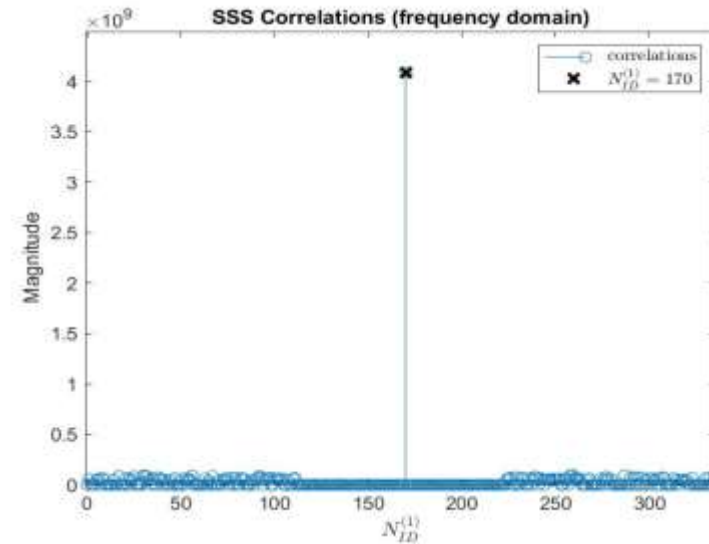
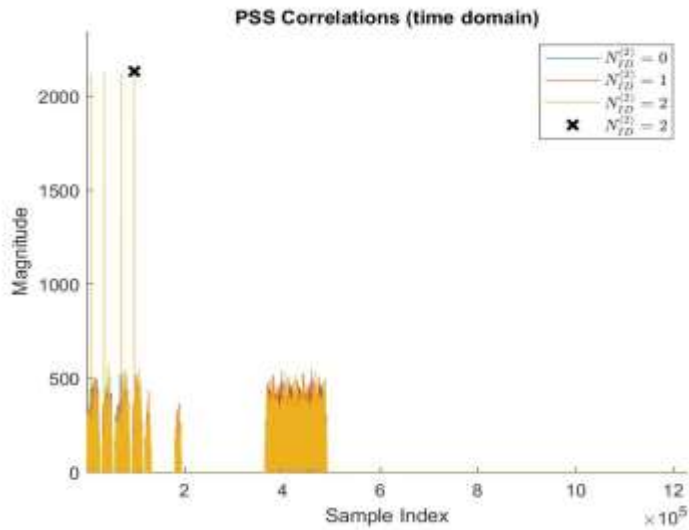
GUI → Frame Display



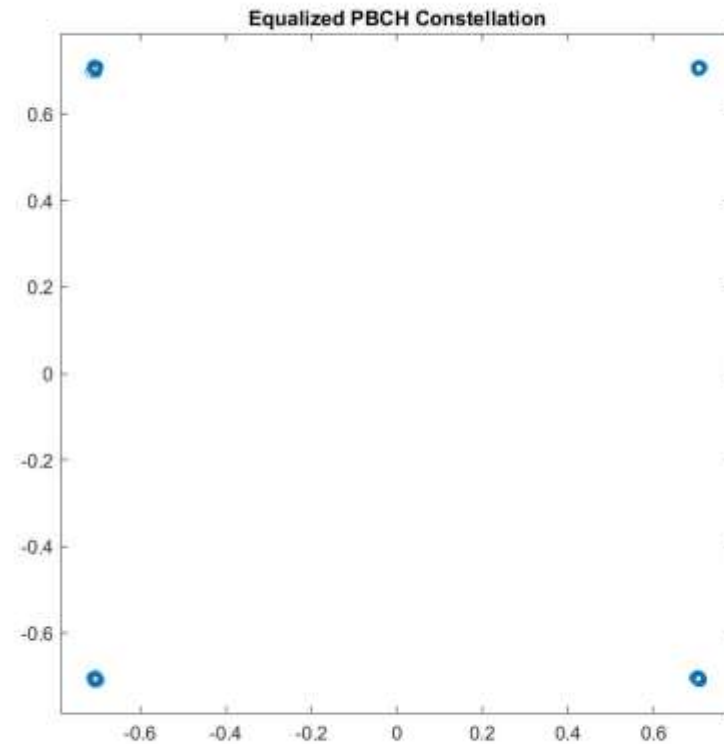
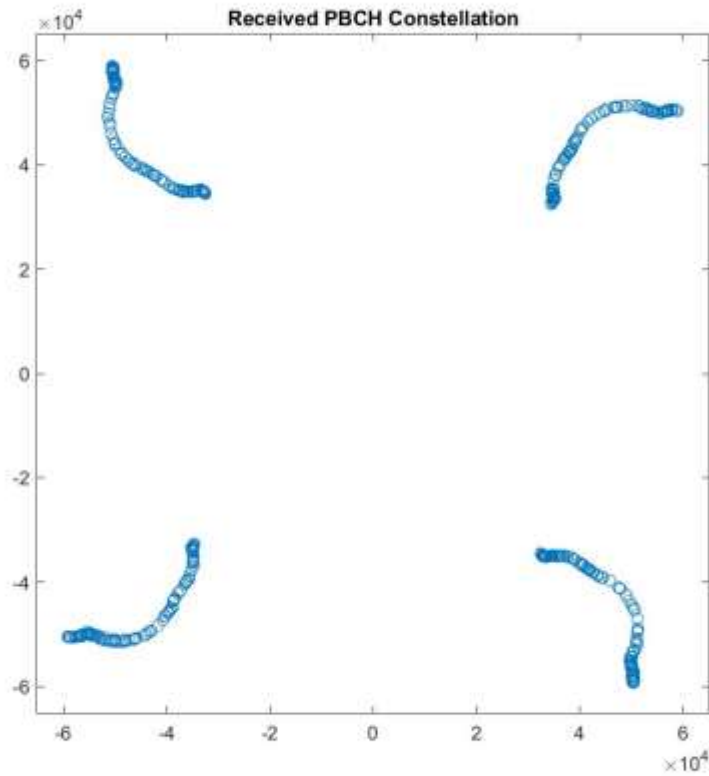
5G NR Frame Structure



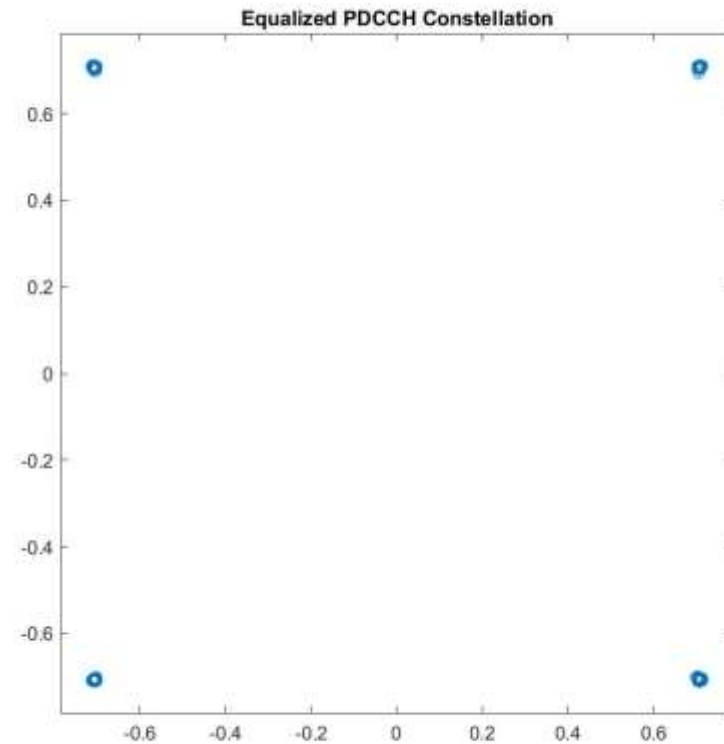
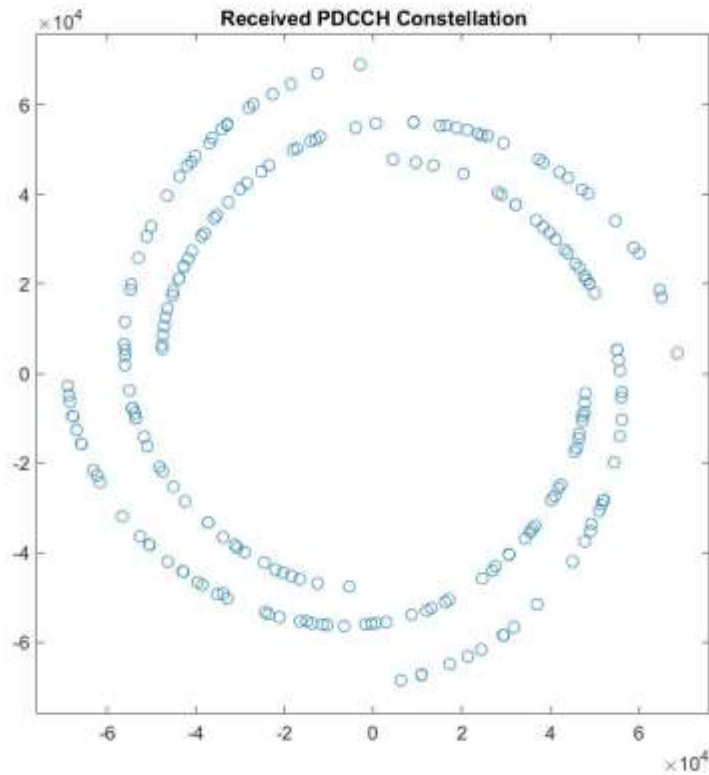
MATLAB Verification ->SSB Sync Detection



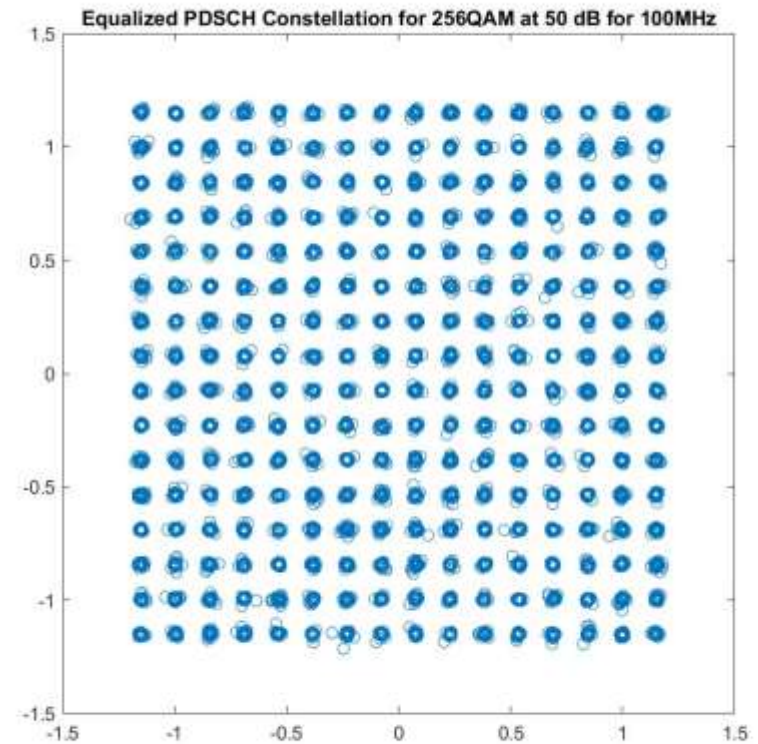
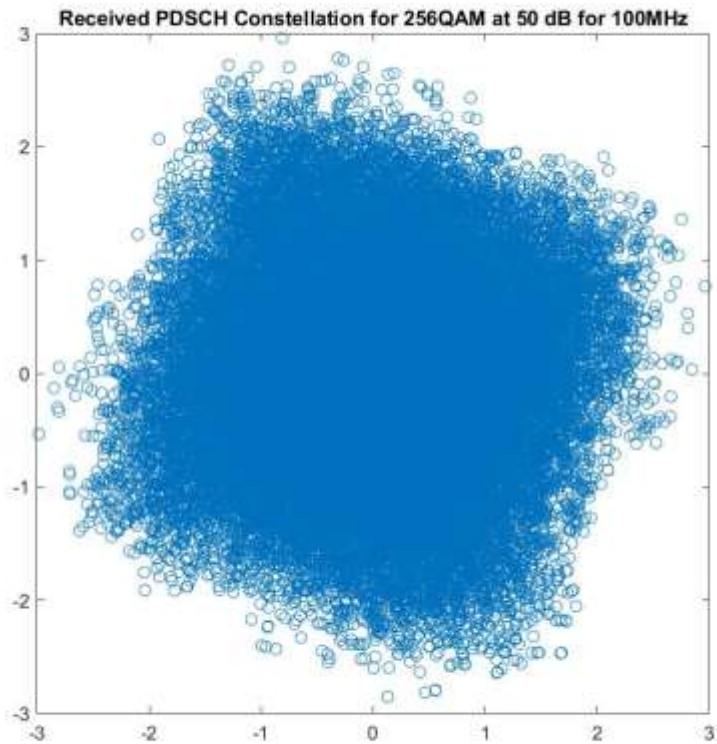
MATLAB Verification -> PBCH Decoding



MATLAB Verification -> PDCCH Decoding

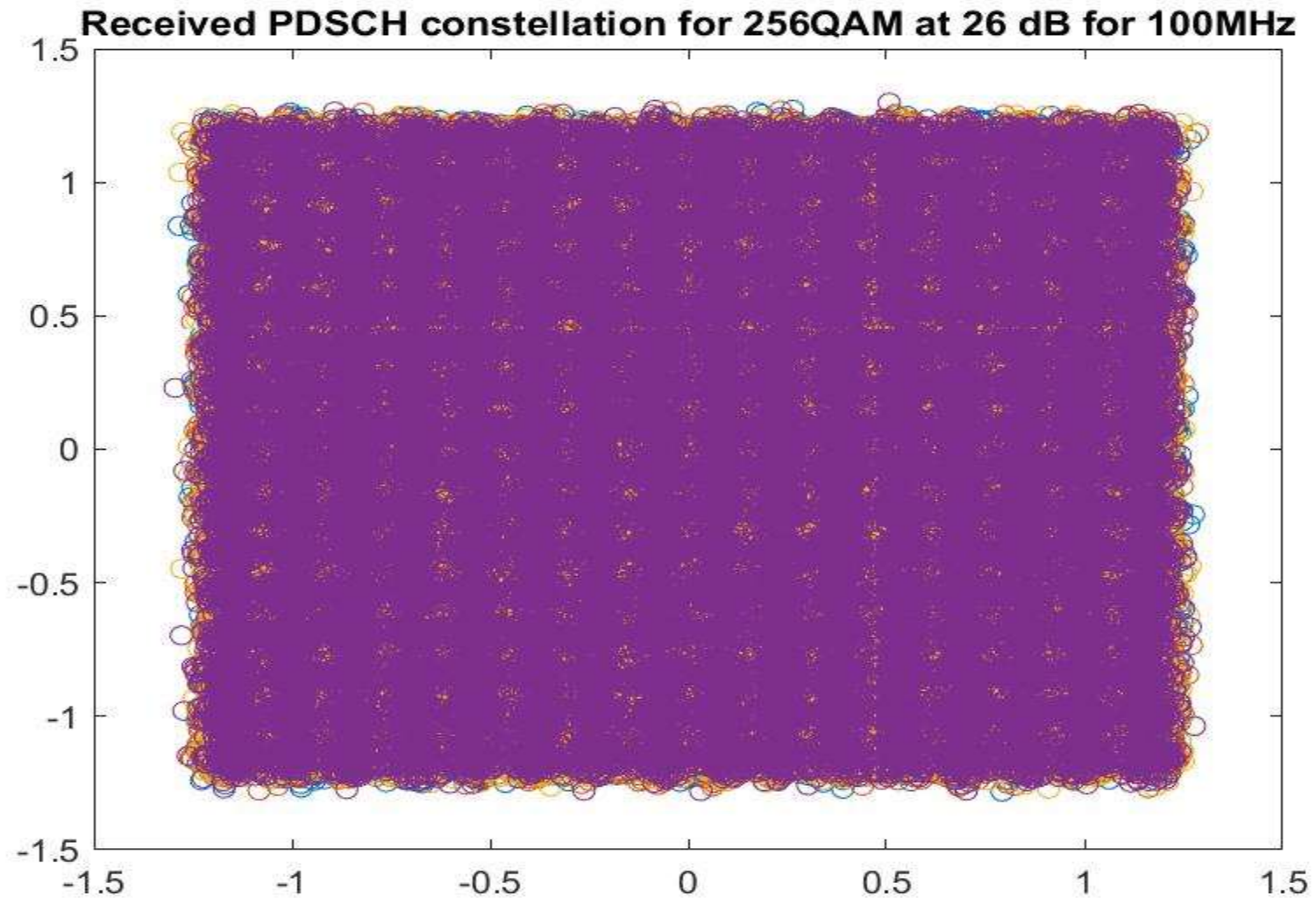


MATLAB Verification -> PDSCH 1 Layer



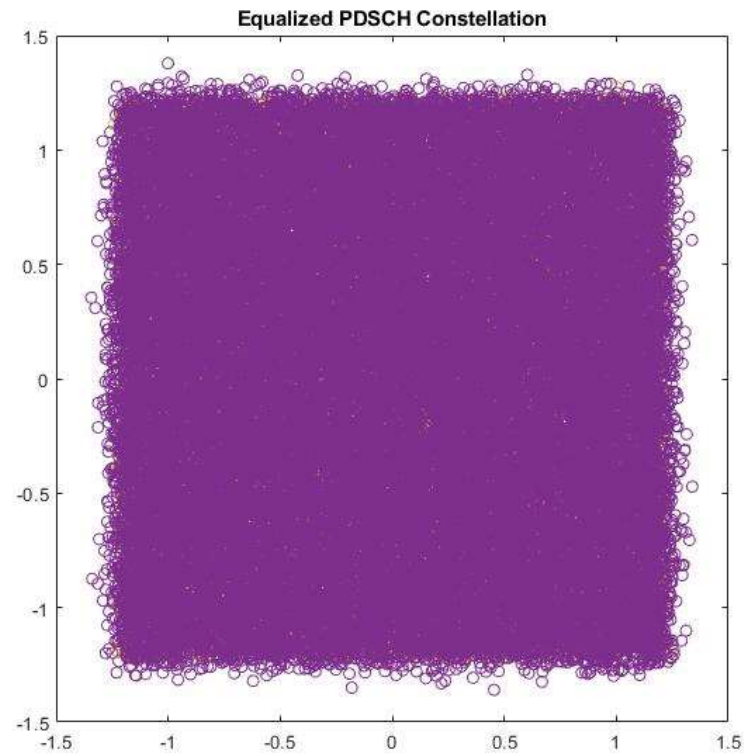
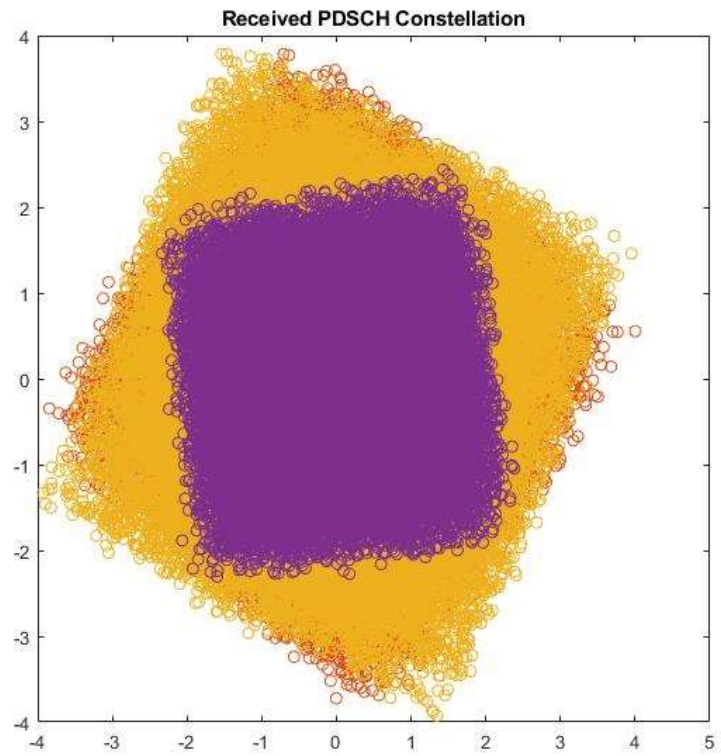
Single User MIMO 4 Layer with AWGN channel

SNR -> 26dB



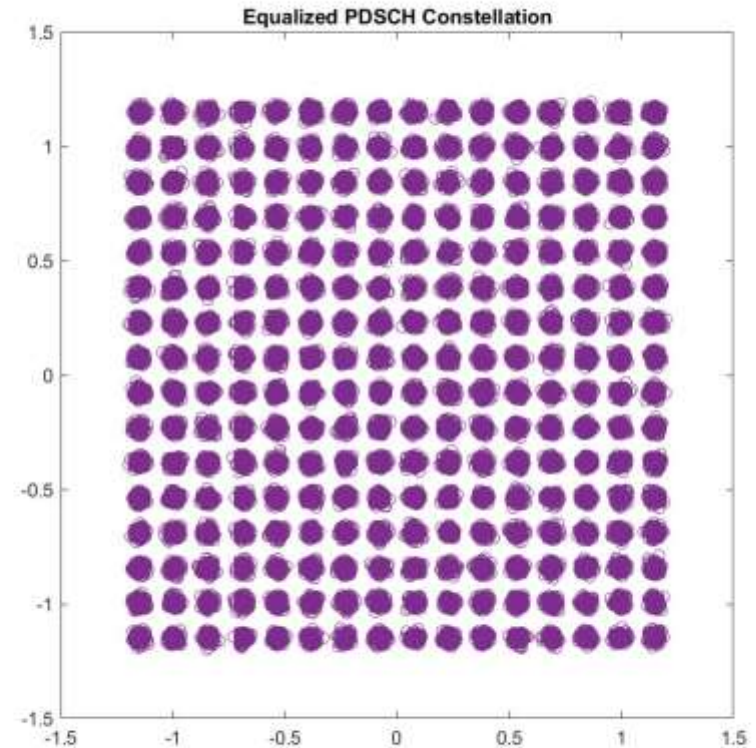
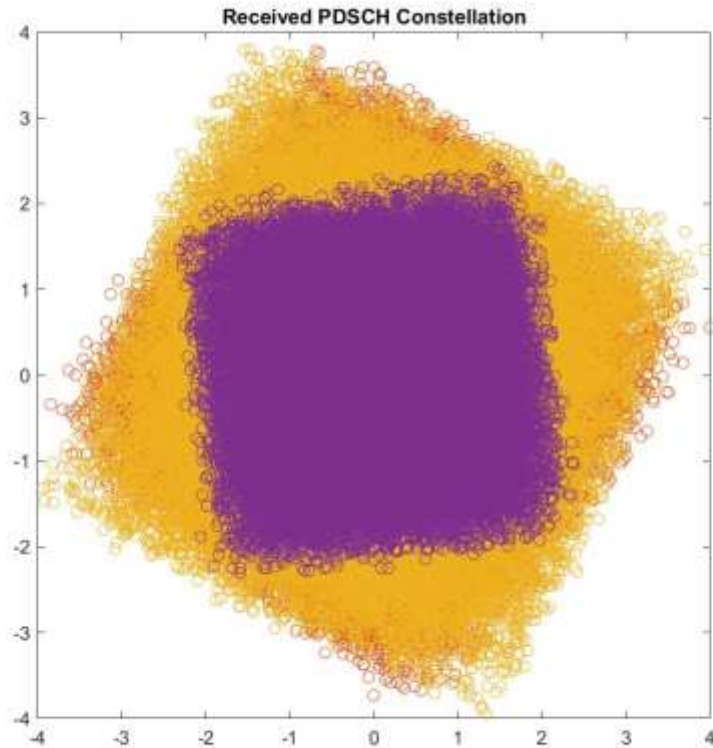
Single User MIMO with 4 Layers decoding at SNR->37dB

Modulation : 256QAM SNRdB = 37dB Bandwidth = 100MHz ChannelType = CDL



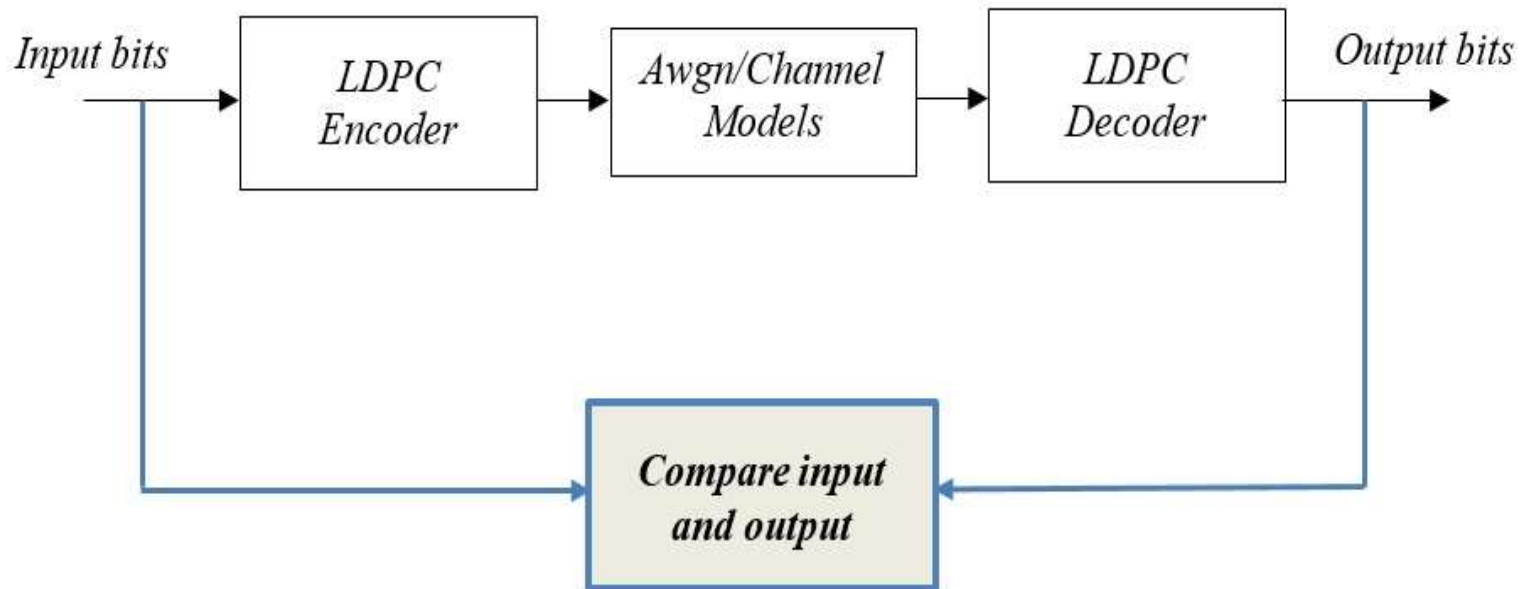
Single User MIMO with 4 Layers decoding at SNR->50dB

Modulation : 256QAM SNRdB = 50dB Bandwidth = 100MHz ChannelType = CDL



- 'Polar Coding' technique has been included in latest 3GPP release for 5G standards in two channels namely SSB and PDCCH.
- 'The LDPC Coding' method has been adopted by 3GPP for 5G New Radio (NR) Uplink and downlink shared channel, i.e PDSCH and PUSCH.
- The C Encoder and Decoder test benches for Polar and LDPC are functionally validated independently with MATLAB as reference.
- Also, the Standalone end to end C test benches for Polar and LDPC are created for the Performance Validation and the BER Plots are plotted and are compared against the MATLAB.

Performance Validation of C Encoder - Decoder



- Why Lekha 5G NR gNB IP
 - Complete C Reference Availability – Enables Platform Flexibility
 - RTL based UL BRP, DL BRP and Precoder Blocks for Scalable Design
 - Reference Solutions for FR1 and FR2 (IF based)

- Why MATLAB 5G Toolbox For Validation
 - IP Maturity at Module Level, Integration Level and Product Solution Level
 - Automated Test Bench For Different User Configurations using MATLAB Toolbox – Enables Regression Test suit for PHY Layer Stack
 - Easier Issue Analysis & Bug finding due to low level access in MATLAB 5G Toolbox

5G Toolbox – PHY Layer Functions

NR Processing Subsystems

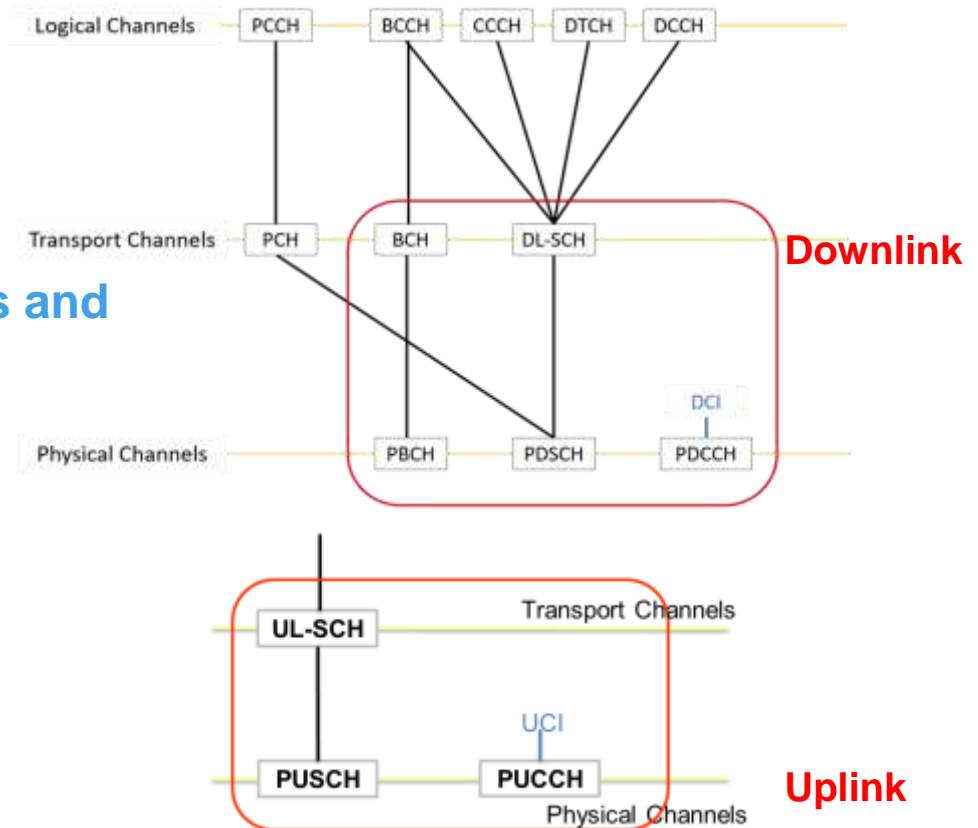
- LPDC & polar coding
- CRC, segmentation, rate matching
- Scrambling, modulation, precoding

NR Downlink and Uplink Channels and Physical Signals

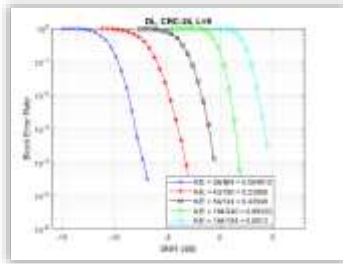
- Synchronization & broadcast signals
- DL-SCH & PDSCH channels
- DCI & PDCCH channels
- UCI, PUSCH, and PUCCH channels

MIMO Propagation channels

- TDL & CDL channel models

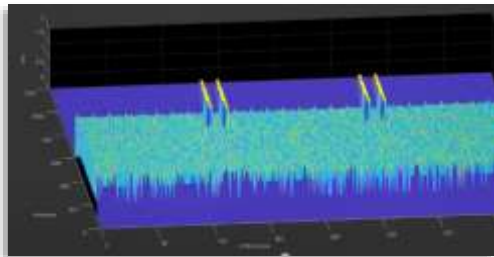


5G Toolbox applications & use-cases



End-to-end link-level simulation

- Transmitter, channel model, and receiver
- Analyze bit error rate (BER), and throughput



Waveform generation and analysis

- Parameterizable waveforms with New Radio (NR) subcarrier spacings and frame numerologies



Golden reference design verification

- Customizable and editable algorithms as golden reference for implementation

5G Toolbox has open customizable algorithms

- All functions are open, editable, customizable MATLAB code
- C/C++ code generation:
Supported with MATLAB Coder



How to learn more

- Go to 5G Toolbox product page
www.mathworks.com/products/5g
[5G Development with MATLAB](#) (ebook)

Documentation All

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Documentation Home

MATLAB
Simulink

5G Toolbox

- Getting Started with 5G Toolbox
- Downlink Channels
- Physical Layer Subcomponents
- Signal Reception
- End-to-End Simulation
- Test and Measurement
- Code Generation and Deployment

Aerospace (Rocket)

Aerospace Toolbox

Antenna Toolbox

Audio System Toolbox

Automated Driving System Toolbox

Biomechanics Toolbox

Communications Toolbox

5G Toolbox **NEW PRODUCT**

5G Toolbox

Simulate, analyze, and test the physical layer of 5G communications systems

Watch video

Download a free trial

Downlink Channels
5G NR downlink channel processing for physical signals and channels, transport channels, and control channels

Physical Layer Subcomponents
Low-level subcomponents for 5G NR channel processing

- Watch Videos & Webinars
[5G: Model, Simulate, Design, and Test 5G Systems with MATLAB](#)
[Waveform Generation and Testing with SDR and RF instruments](#)

Thank You