5G NR Testing using SystemVue and Signal Studio

A THESIS

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THESIS CERTIFICATE

This is to certify that the thesis entitled **“5G NR Testing using Systemvue and Signal Studio”** submitted by **Rohit Singh** to the Indian Institute of Technology, Madras for the award of the degree of **Bachelor of Technology** is a bona fide record of research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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“You have to dream before your dreams can come true.”

- *APJ Abdul Kalam*

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ABSTRACT

This work focuses on the testing strategy of 5G NR Wireless Access Technology and simulating 5G Physical Channels and Signals which is used for testing the codes in **5G Testbed , IIT Madras** . Various Test vectors are generated using Keysight's PathWave System Design and Keysight's Signal Studio Pro.

SystemVue offers the basic building blocks to jumpstart model development. We can easily customize models to include custom intellectual property (IP) and build systems confidently knowing that you are using industry validated modeling technology. PathWave System Design (SystemVue) software can be used to develop and simulate various models of various Wireless communication technologies including the new 5G NR. Keysight Technologies, Inc. Signal Studio Pro for 5G NR software is a flexible signal creation tool that will reduce the time spent on signal simulation. It quickly and easily generates 5G NR signal for component, transmitter and receiver test

The Downlink Physical Signals Section focuses on the Generation of the Test vectors for various Physical Signals such as DMRS, CSIRS, PSS, SSS.

The Downlink Physical Channels section focuses on the Generation of the Test vectors for various Downlink Physical Signals such as PDSCH, PDCCH and PBCH.

The Uplink Physical Signals section focuses on the Generation of the Test vectors for various Uplink Physical Signals such as SRS, DMRS for PUSCH and DMRS for PUCCH.

The Uplink Physical Channels section focuses on the Generation of the Test vectors for the various Uplink Physical Channels such as PUSCH, PUCCH.

The PHYSICAL CHANNELS IMPLEMENTATION USING SIGNAL STUDIO section focuses on the Generation of the Test vectors for various Uplink and Downlink Channels both such as PDSCH, DCI(PDCCH), PDCCH, PBCH, CSIRS, PUSCH, UCI (PUCCH), SRS and PRACH.

These test vectors form the basis for verification for each stage of the software simulation and hardware implementation at 5G Testbed.

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ABBREVIATIONS

Acronyms

3GPP	Third Generation Partnership Project
SSS	Secondary Synchronization Signal
PSS	Primary Synchronization Signal
DMRS	Demodulation Reference Signal
SSB	Synchronization Signal Block
PBCH	Physical Broadcast Channel
PDSCH	Physical Downlink Shared Channel
PDCCH	Physical Downlink Control Channel
MIB	Master Information Block
UCI	Uplink Control Information
DCI	Downlink Control Information
NR	New Radio
TDD	Time Division Duplex
FDD	Frequency Division Duplex
LDPC	Low Density Parity Check
MIMO	Multi Input Multi Output
LTE	Long Term Evolution
PUSCH	Physical Uplink Shared Channel

CHAPTER 1

INTRODUCTION

One of the ways that the electronics industry has dealt with the increasing demand for data communication throughput between system components is a new modeling approach – the input/output buffer information specification-algorithmic modeling interface (IBIS-AMI). PathWave System Design (SystemVue) is a focused electronic design automation (EDA) environment for electronic system-level (ESL) design. You can use it to automate code-generation and model compilation within minutes. PathWave System Design (SystemVue) offers the basic building blocks to jumpstart model development. You can easily customize models to include custom intellectual property (IP) and build systems confidently knowing that you are using industry validated modeling technology. PathWave System Design (SystemVue) software can be used to develop and simulate various models of various Wireless communication technologies including the new 5G NR (New Radio). It can also be used to test various Physical Channels and Physical Signals of both Uplink and Downlink. Various sets of the input data are given in the model after the schematic model is generated and then the respective sets of output data are generated. These sets of the output data are to be used as a reference for various matlab codes. In this way the correctness of the matlab code is found out. In this way the testing of the codes are done with the help of PathWave System Design (SystemVue).

SystemVue Key Benefits

1. Automate AMI-model generation in minutes
2. Customize models to include custom IP
3. Gain confidence with industry-validated modeling technology
4. Jumpstart development with basic building blocks

5G NR Library in SystemVue

The 5G NR Library is a trusted reference digital signal processing (DSP) modeling product, supporting the 3GPP standards for the 5G NR physical layer specification. The intellectual property (IP) blocks are cross validated with major 5G chipset makers during the early system modeling and prototyping phase. With PathWave System Design (SystemVue) you have access to integrate 5G NR baseband IP, various RF transceiver design examples operating in sub-6GHz and mmWave frequency, and phased array and beamforming models using antenna patterns from EM software or measurement. It provides the best system-level engineering environment in a single simulation cockpit.

5G NR Library in SystemVue Key Benefits:

1. Model baseband, RF, and antennas in a single tool
2. Use trusted algorithm reference IP
3. Model RF system architecture
4. Perform advanced end to-end link performance
5. Setup over-the-air simulation

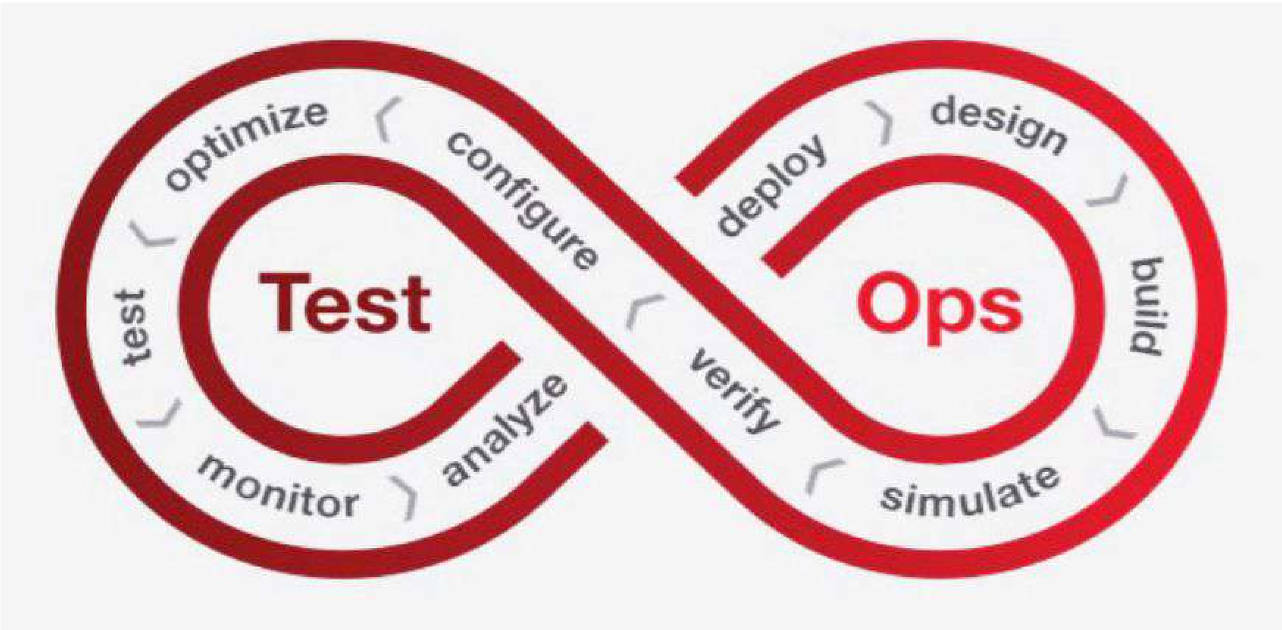

Figure 1: Testing Strategy

Keysight Technologies, Inc. Signal Studio Pro for 5G NR software is a flexible signal creation tool that will reduce the time spent on signal simulation. It quickly and easily generates 5G NR signal for component, transmitter and receiver test. It generates 3GPP 5G NR standard-compliant signals for testing base stations, mobile transmitters and receivers with channel coding and multi-antenna port support. One can download and playback. Signal Studio Pro uses waveform playback mode to create and customize waveform files needed to test components and transmitters. It is a user friendly interface that lets you configure signal parameters, calculate the resulting waveforms and download the files for playback on Vector Signal Analyser or Vector Signal Analyser software. The application of these tests include parametric tests of carriers such as Downlink and Uplink. Once we set up the signals in Signal Studio Pro, we can download them into a variety of Keysight Instruments. This offers flexibility in generating various signals at various carrier frequencies with different bandwidths for multiple applications.

Signal Studio Pro Key Benefits:

1. Quickly configure and generate 5G NR test models for FDD and TDD
2. Create spectrally-correct signals for channel power, spectral mask, and spurious testing.
3. View CCDF, spectrum, time domain, and power envelope graphs to investigate the effects of power ramps, modulation formats, power changes, clipping, and other effects on device performance.

CHAPTER 2

DOWNLINK PHYSICAL SIGNALS

According to 3GPP TS 38.211 (v 15.8.0), Downlink Consists of three kinds of Physical signals, these are Reference Signals, Synchronization Signals and SS/PBCH Block. This section provides the simulation of various Downlink Physical Signals using Systemvue.

All the SystemVue modules are in accordance with 3GPP TS 38.212 v15.3.0, 3GPP TS 38.211 v15.3.0 .

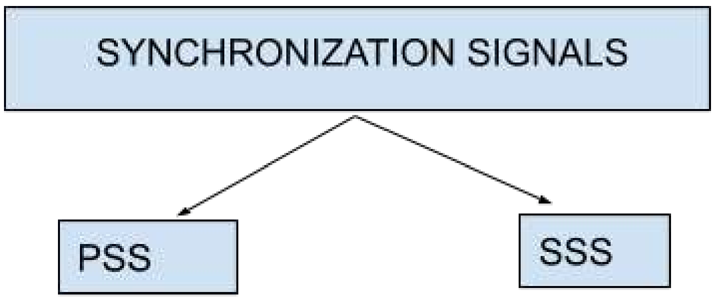

Figure 2: Types of Synchronization Signals

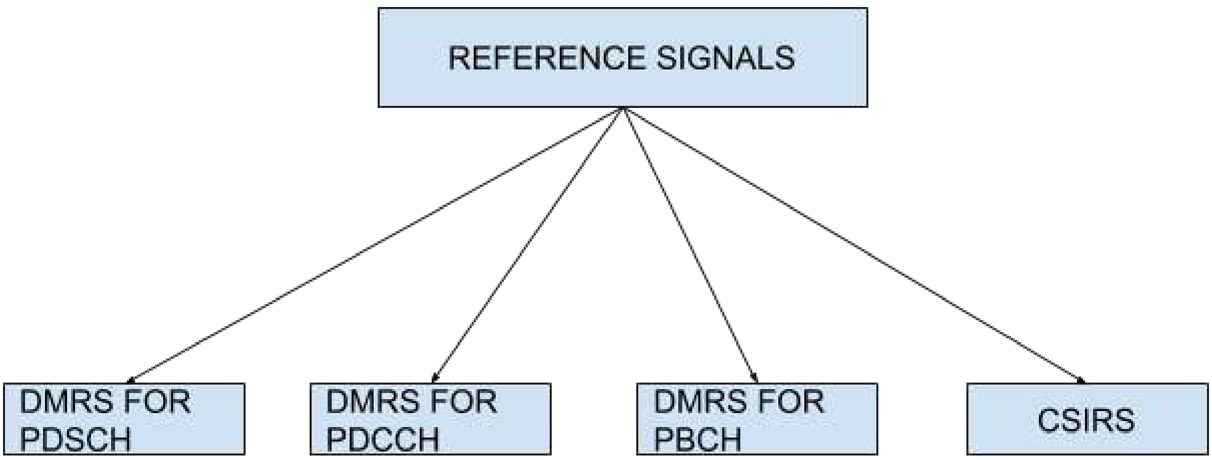

Figure 3: Types of Downlink Reference Signals

1. **SSS(Secondary Synchronization Sequence):**

   SSS is a specific physical layer signal that is used for radio frame synchronization. It has characteristics as listed below.

- Mapped to 127 active sub carriers around the lower end of the system bandwidth (subcarrier 80~206)
- Made up of 127 Values
- Used for Downlink Frame Synchronization
- One of the critical factors determining Physical Cell ID.

The following diagram shows the generation of SSS using Systemvue and its block diagram:

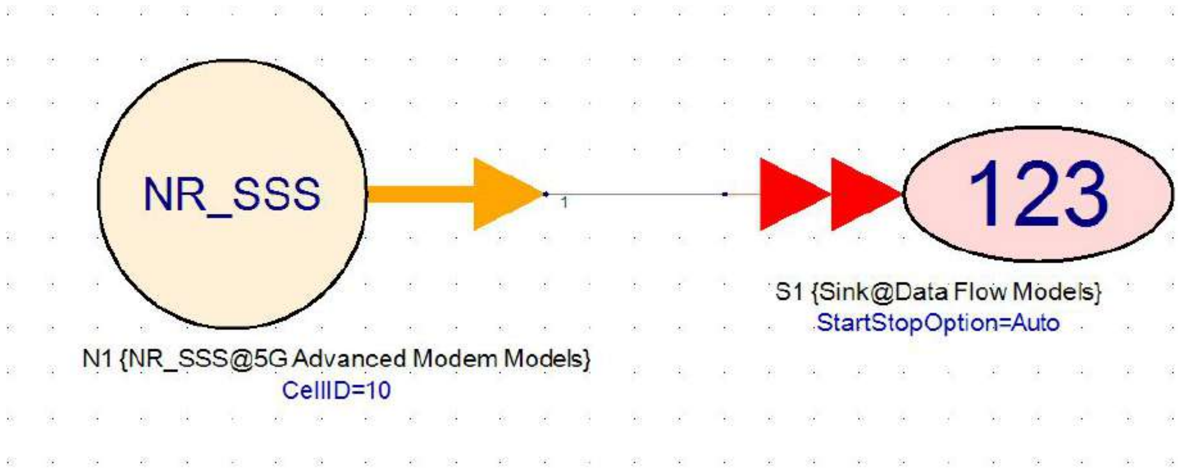

Figure 4: SSS generation Schematic Diagram

Systemvue Module	Library	Use
NR_SSS	5G Advanced Modem Models	This model is used to generate NR SSS in frequency domain
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 1:SystemVue Blocks for generation of SSS

Working: First of all, the module NR_SSS is used to generate the SSS sequence in frequency domain which is a 127 length sequence. The output of NR_SSS is fed to Sink which is used to collect the data and also we can save the output data to the text file.

2. **PSS (Primary Synchronization Sequence):**

PSS is a specific physical layer signal that is used for radio frame synchronization. It has characteristics as listed below.

- Mapped to 127 active sub carriers around the center of SSB
- Made up of 127 Values
- Used for Downlink Frame Synchronization
- One of the critical factors determining Physical Cell ID

The following diagram shows the generation of PSS using Systemvue and its block diagram:

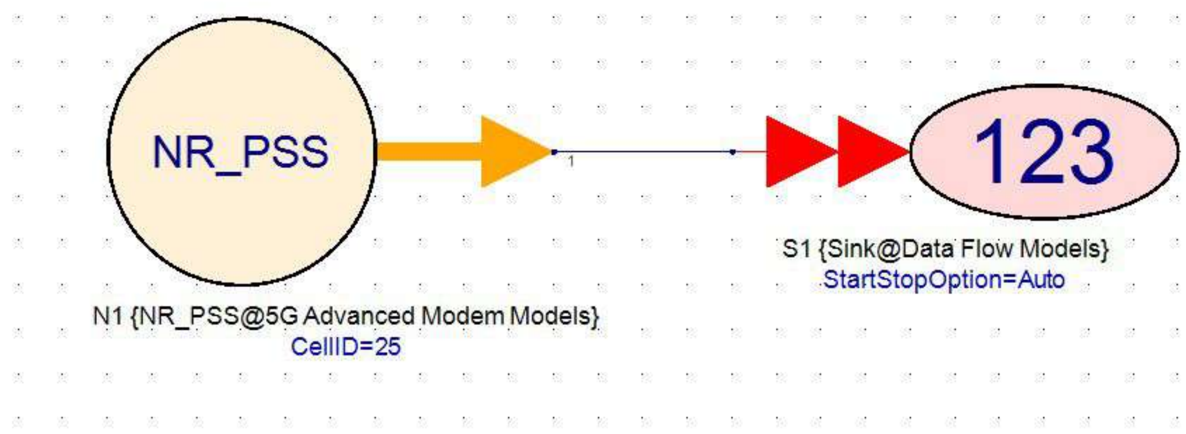

Figure 5: PSS generation Schematic Diagram

SystemVue Module	Library	Use
NR_PSS	5G Advance Modem Models	This model is used to generate NR PSS in frequency domain.
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 2:SystemVue Blocks for generation of PSS

Working: First of all, the module NR_PSS is used to generate the PSS values in frequency domain, which is a 127 length sequence. The only input parameter in the NR_PSS is CellID which ranges from 0 to 1007. The output is then fed to the Sink module via net. The output data can be saved as a table, graph and a text file. The text file can be used for the further testing of NR_PSS.

3. CSIRS

NR CSI (Channel Status Information) is a mechanism that a UE measures various radio channel quality and reports the result to Network(gNB). CSIRS uses the QPSK modulated data. CSIRS is configured for various Ports and cdm-types which are chosen according to the 'Table 7.4.1.5.3-1: CSI-RS locations within a slot'.

The following diagram shows the table 7.4.1.5.3-1 from TS-38.211,some of the inputs to the modules in SystemVue are chosen from this table.

Row	Ports X	Density ρ	*cdm-Type*	$(\bar{k},\bar{l})$	CDM group index j	k'	l'
1	1	3	noCDM	(k_0,l_0), (k_0+4,l_0), (k_0+8,l_0)	0,0,0	0	0
2	1	1, 0.5	noCDM	(k_0,l_0),	0	0	0
3	2	1, 0.5	fd-CDM2	(k_0,l_0),	0	0, 1	0
4	4	1	fd-CDM2	(k_0,l_0), (k_0+2,l_0)	0,1	0, 1	0
5	4	1	fd-CDM2	(k_0,l_0), (k_0,l_0+1)	0,1	0, 1	0
6	8	1	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0)	0,1,2,3	0, 1	0
7	8	1	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_0,l_0+1), (k_1,l_0+1)	0,1,2,3	0, 1	0
8	8	1	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0)	0,1	0, 1	0, 1
9	12	1	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0), (k_4,l_0), (k_5,l_0)	0,1,2,3,4,5	0, 1	0
10	12	1	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0)	0,1,2	0, 1	0, 1
11	16	1, 0.5	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0), (k_0,l_0+1), (k_1,l_0+1), (k_2,l_0+1), (k_3,l_0+1)	0,1,2,3, 4,5,6,7	0, 1	0
12	16	1, 0.5	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0)	0,1,2,3	0, 1	0, 1
13	24	1, 0.5	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_0,l_0+1), (k_1,l_0+1), (k_2,l_0+1),(k_0,l_1), (k_1,l_1), (k_2,l_1), (k_0,l_1+1), (k_1,l_1+1), (k_2,l_1+1)	0,1,2,3,4,5, 6,7,8,9,10,11	0, 1	0
14	24	1, 0.5	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_0,l_1), (k_1,l_1), (k_2,l_1)	0,1,2,3,4,5	0, 1	0, 1
15	24	1, 0.5	cdm8-FD2-TD4	(k_0,l_0), (k_1,l_0), (k_2,l_0)	0,1,2	0, 1	0, 1, 2, 3
16	32	1, 0.5	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0),(k_0,l_0+1), (k_1,l_0+1), (k_2,l_0+1), (k_3,l_0+1), (k_0,l_1), (k_1,l_1), (k_2,l_1), (k_3,l_1), (k_0,l_1+1), (k_1,l_1+1), (k_2,l_1+1), (k_3,l_1+1)	0,1,2,3, 4,5,6,7, 8,9,10,11, 12,13,14,15	0, 1	0
17	32	1, 0.5	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0), (k_0,l_1), (k_1,l_1), (k_2,l_1), (k_3,l_1)	0,1,2,3,4,5,6,7	0, 1	0, 1
18	32	1, 0.5	cdm8-FD2-TD4	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0)	0,1,2,3	0,1	0,1, 2, 3

Figure 6: Table 7.4.1.5.3-1

The following figures provide the block diagram of the CSIRS generation in SystemVue by giving multiple sets of inputs.

First diagram shows the CSIRS Generation for two ports and the second diagram shows CSIRS generation for 8 ports.

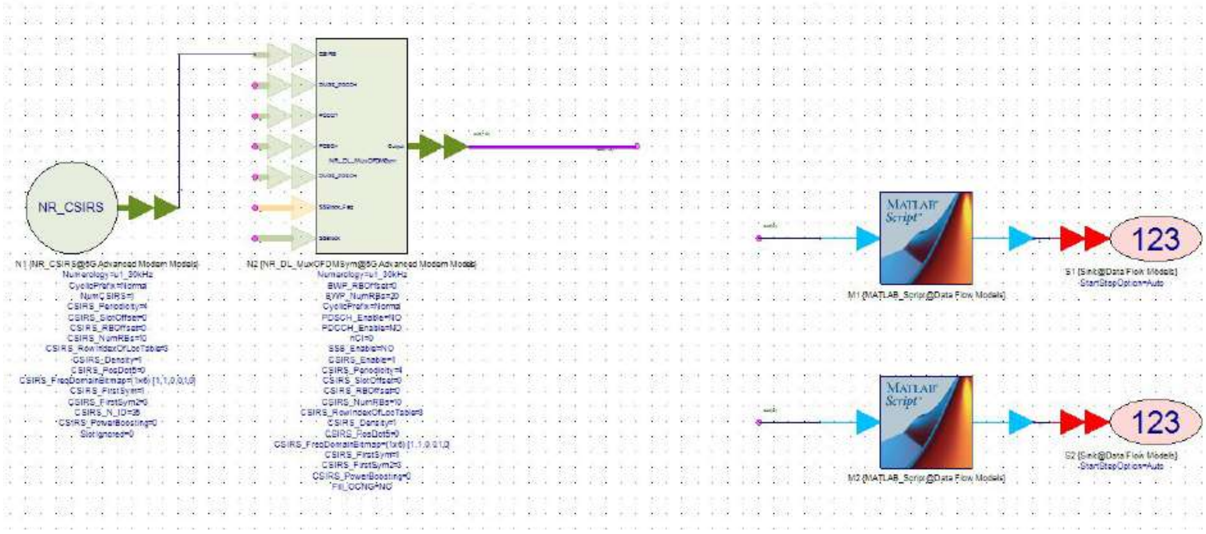

Figure 7: CSIRS generation Schematic Diagram (two ports)

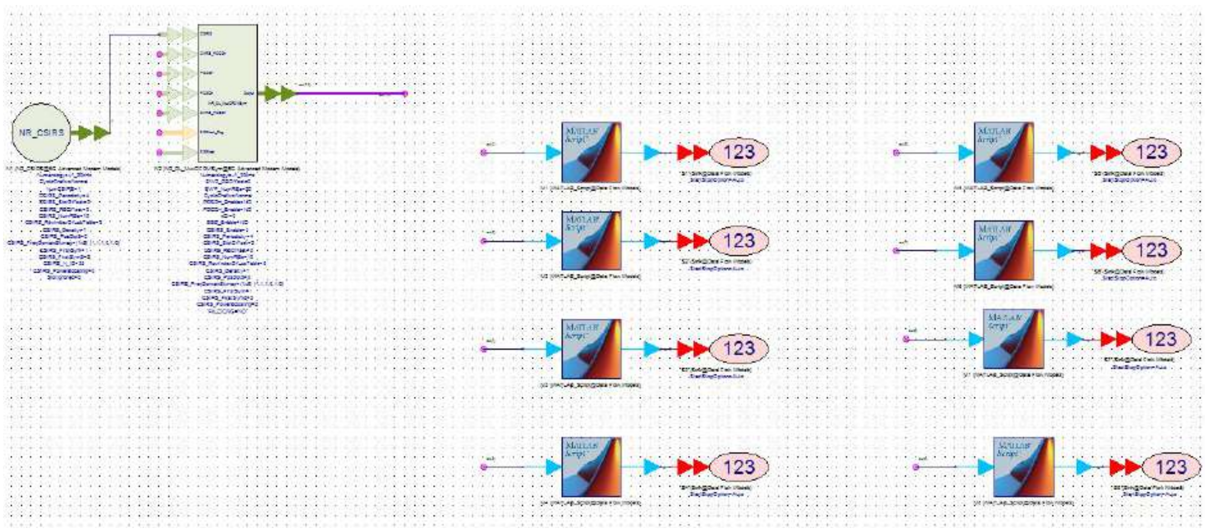

Figure 8: CSIRS generation Schematic Diagram (eight ports)

The following table shows various systemvue modules required and their library and their use.

SystemVue Module	Library	Use

NR_CSIRS	5G Advanced Modem Models	This model is used to generate CSI-RS in one slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file
NR_DL_MuxOFDMSym	5G Advanced Modem Models	This model is responsible for multiplexing different NR downlink physical channels and physical signals to integrate them for following time-domain signal construction.

Table 3:SystemVue Blocks for generation of CSIRS

Working: First of all, the module NR_CSIRS is fed with various input parameters. According to the input parameters, this module generates CSIRS values within a slot for different ports and CDMtypes. The output is then fed to 'NR_MuxOFDMSym' module which is used to mux the data from various channels and put them in the resource Grid. The outputs for various ports are then saved to .mat files using the Matlab_Script module. At last the outputs are saved to a table or a text file using the Sink module.

4. **DMRS For PDSCH**

PDSCH DMRS is a special type of physical layer signal which functions as a reference signal for decoding PDSCH.

The following figure shows the Generation of DMRS for PDSCH using SystemVue

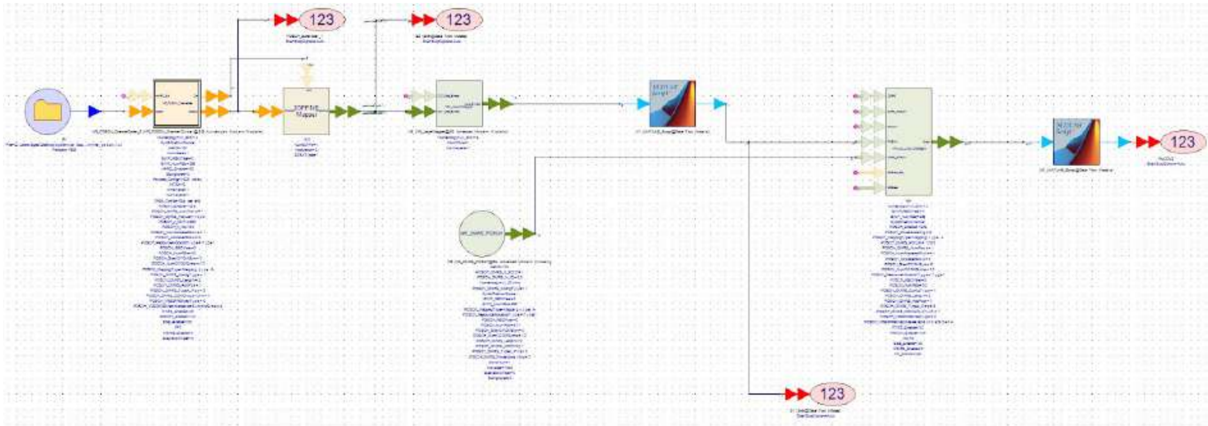

Figure 9: DMRS for PDSCH generation Schematic Diagram

The following table shows various systemvue modules which are used in the generation of DMRS for PDSCH.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PDSCH_ChannelCoder	5G Advance Modem Models	This subnetwork is used to perform whole channel coding process for PDSCH as described in 7.2 of TS 38.211
NR_Mapper	5G Advance Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_LayerMapper	5G Advance Modem Models	This model is used to perform layer mapping on PDSCH as described in 7.3.1.3 of TS 38.211
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output

		data
NR_DMRS_PDSCH	5G Advance Modem Models	This model is used to generate DMRS for PDSCH in one slot
NR_DL_MuxOFDMSym	5G Advance Modem Models	This model is responsible for multiplexing different NR downlink physical channels and physical signals to integrate them for following time-domain signal construction.
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 4:SystemVue Blocks for generation of DMRS PDSCH

Working : Our approach for generating DMRS for PDSCH is little different than previous signals generation. We will generate the DMRS along with PDSCH data, but we replace the PDSCH data with the zeroes so as to get only the DMRS values inside the Resource Grid. For generating the PDSCH data, we need to provide the input Transport Block using the ReadFile module which reads the Transport block from a text file. After taking the Transport block as input, the bits in the transport block are sent to the NR_PDSCH_ChannelCoder which performs the whole channel coding process(CRC Encoding ,CodeBlockSegmentation, LDPC Encoding, Rate Matching and Scrambling). After the whole channel coding, the data is then sent to the NR_Mapper which then maps the bits to the Constellation points. After mapping to the constellation points, Layer Mapping is done with the help of NR_LayerMapper. Now the symbols are ready to be placed within the resource Grid. Now we replace them with zeros. On the other hand, the DMRS values are generated with the help of NR_DMRS_PDSCH module. Both the DMRS values and zeros (at the place of PDSCH) are placed within the Grid. Now the grid containing only DMRS values is saved to .mat file using the Matlab_Script module. Finally the text file of output is saved at desired location using Sink Module.

5. DMRS for PDCCH

PDSCH DMRS is a special type of physical layer signal which functions as a reference signal for decoding PDSCH. It can also be used for channel estimation (using Pilot channel estimation technique).

The following figure shows the DMRS for PDCCH Generation using SystemVue:

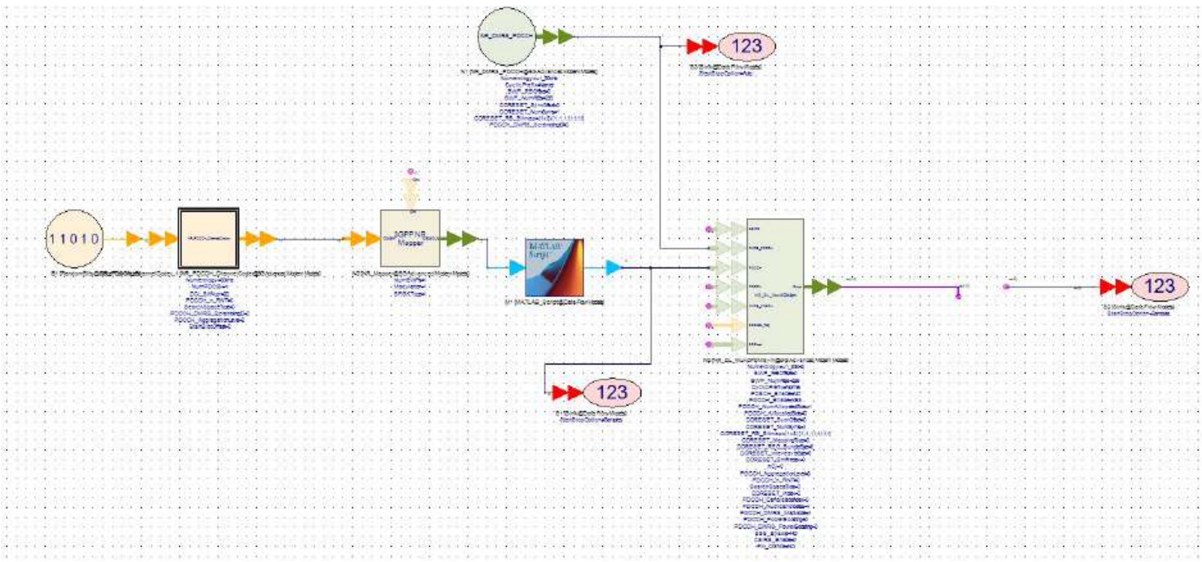

Figure 10: DMRS for PDCCH generation Schematic Diagram

SystemVue Module	Library	Use
Random Bits	Data Flow Models	This model generates a random bit sequence, in which the probability of a 0 bit is ProbOfZero and the probability of a 1 bit is 1 - ProbOfZero.
NR_PDCCH_ChannelCoder	5G Advance Modem Models	This subnetwork is used to perform the whole channel coding process for PDCCH as described in 7.3 of TS 38.211
NR_Mapper	5G Advance Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS

		38.211
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
NR_DMRS_PDCCH	5G Advance Modem Models	This model is used to generate DMRS for PDCCH
NR_DL_MuxOFDMSym	5G Advance Modem Models	This model is responsible for multiplexing different NR downlink physical channels and physical signals to integrate them for following time-domain signal construction.
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 5:SystemVue Blocks for generation of DMRS for PDCCH

Working: First of all the random DCI bits are input to the NR_PDCCH_ChannelCoder which performs the whole Channel Coding process.

In the channel coding the first operation is CRC encoder followed by the NR_PolarEncoder followed by the NR_Polar_RateMatch and finally NR_Scrambler.

After the Channel coding , the bits are sent to NR_Mapper for mapping them to constellation points.Now the constellation points are ready to be put into the Resource Grid. Now we replace the Constellation points with zeros so as to put only DMRS values to the Resource Grid. On the other hand, NR_DMRS_PDCCH module generates the DMRS values for PDCCH according to the input parameters. Both DMRS values and PDCCH values(now zeroes) are mapped to the Resource Grid using NR_DL_MuxOFDMSym. The output resource Grid is then saved to a text file using the Sink module.

The output of PDCCH is taken through the 2000 port.

In this way the PDCCH DMRS is generated and mapped to the resource grid.

6. DMRS for PBCH

PBCH DMRS is a special type of physical layer signal which functions as a reference signal for decoding PBCH. In LTE, we don't need this kind of special DMRS for PBCH because we can use CRS(Cell Specific Reference Signal) for PBCH decoding. However, in 5G/NR there is no CRS. That's why we need the DMRS dedicated for PBCH decoding.

SystemVue implementation of DMRS for PBCH:

The following figure shows the generation of DMRS for PBCH using SystemVue.

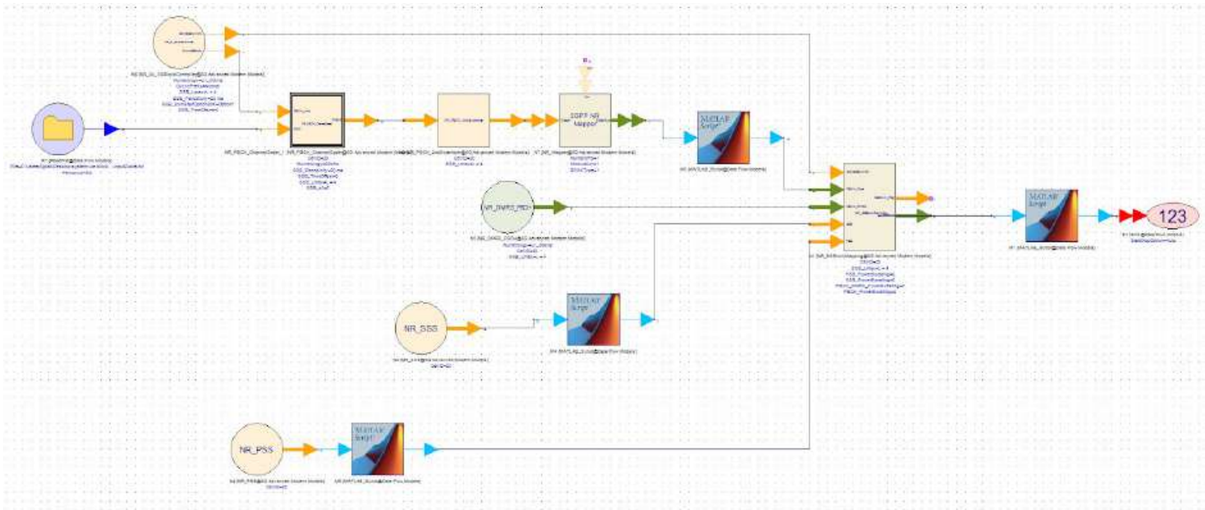

Figure 11: DMRS for PBCH generation Schematic Diagram

The following table shows various SystemVue modules required in DMRS for PBCH generation, their libraries and use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_DL_SSBlockController	5G Advanced Modem Models	This model is used to get the number of SS/PBCH blocks and the start index of SS/PBCH blocks in one slot.

NR_PBCH_ChannelCoder	5G Advanced Modem Models	This subnetwork is used to perform the whole channel coding process for PBCH channels as described in 7.1 of TS 38.212
NR_PBCH_2ndScrambler	5G Advanced Modem Models	This model is used to perform scrambling on PBCH bit sequence prior to modulation as described in 7.3.3.1 of TS 38.211
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_DMRS_PBCH	5G Advanced Modem Models	This model is used to generate DMRS for PBCH
NR_SSS	5G Advanced Modem Models	This model is used to generate NR SSS in frequency domain
NR_PSS	5G Advanced Modem Models	This model is used to generate NR PSS in frequency domain
NR_SSBlockMapping	5G Advanced Modem Models	This model is used to combine PSS, SSS, PBCH data and PBCH DMRS to SS/PBCH block in one slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 6:SystemVue Blocks for generation of DMRS for PBCH

Working: As we want only DMRS values for PBCH, so we put all other things such as SSS, PSS and the PBCH data to zero. NR_SSBlockMapping is used to generate the Resource Grid, but as all other values are set to zero. Only DMRS values will be mapped in the resource grid.

The output grid is then saved as a .mat file and text file with the help of Matlab_Script and Sink modules.

CHAPTER 3

DOWNLINK PHYSICAL CHANNELS

According to 3GPP TS 38.211 (v 15.8.0), Downlink Consists of three kinds of Physical Channels, these are

- PDSCH (Physical Downlink Shared Channel)
- PDCCH (Physical Downlink Control Channel)
- PBCH (Physical Broadcast Channel)

1. PDSCH

PDSCH (Physical Downlink Shared Channel) is the main channel in the downlink which is used for the user data. It is also used for User Equipment specific higher layer information, system information and paging.

SystemVue Implementation of PDSCH:

The following block diagram shows the PDSCH generation using SystemVue.

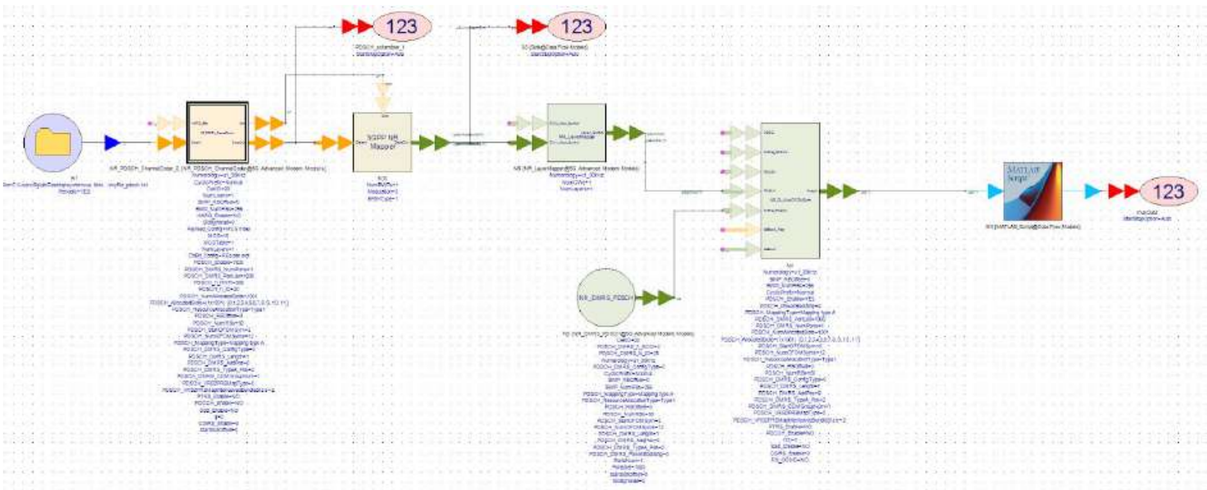

Figure 12: PDSCH generation Schematic Diagram

The following table shows various modules used in generation of PDSCH, their library and their use.

SystemVue Module	Library	Use

ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PDSCH_ChannelCoder	5G Advanced Modem Models	This subnetwork is used to perform whole channel coding process for PDSCH as described in 7.2 of TS 38.211
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_LayerMapper	5G Advanced Modem Models	This model is used to perform layer mapping on PDSCH as described in 7.3.1.3 of TS 38.211
NR_DMRS_PDSCH	5G Advanced Modem Models	This model is used to generate DMRS for PDSCH in one slot
NR_DL_MuxOFDMSym	5G Advanced Modem Models	This model is responsible for multiplexing different NR downlink physical channels and physical signals to integrate them for following time-domain signal construction.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 7:SystemVue Blocks for generation of PDSCH

NR_PDSCH_ChannelCoder is a module that performs the whole channel coding. The following figure shows the operations done by this module.

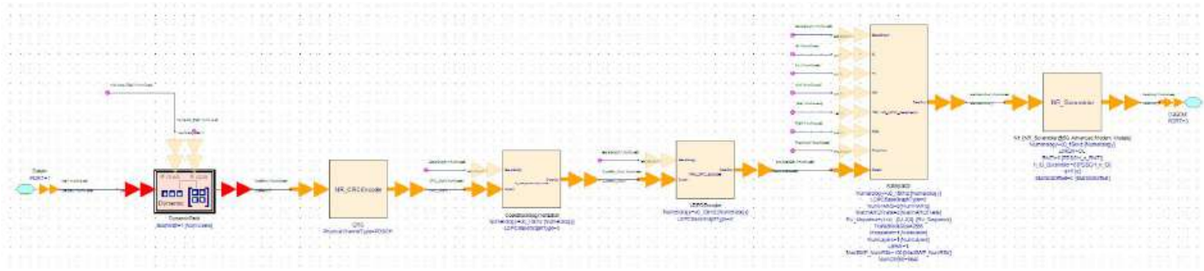

Figure 13: NR_PDSCH_ChannelCoder Submodel Schematic Diagram

First of all, the input bits are sent to NR_CRCEncoder which is used to do the CRC attachment on the transport block. For PDSCH, if the size of transport block is greater than 3824, then 24 CRC bits are appended to the Transport Block, otherwise 16 CRC bits are appended. After the CRC addition, the bits are sent to NR_LDPC_CodeBlockSegmentation which is used to perform Code Block Segmentation on transport blocks that use LDPC coders. This model supports both LDPC base graph type 1 and base graph type 2. After this, LDPC encoding is done with the help of NR_LDPC_Encoder. After LDPC Encoding, Rate Matching for LDPC Encoding is done with the help of NR_LDPC_RateMatch which also does Bit selection and bit interleaving. Finally NR_Scrambler does the Scrambling of the bits.

Working: First of all the input bits are taken from a text file with the help of ReadFile module. The bits are then sent to the NR_PDSCH_Channel which does the channel coding process as described above. The Coded bits are then sent to the NR_Mapper which is used to map the bits to constellation points. The constellation points are then passed through the NR_LayerMapper which does the layer mapping of PDSCH data. The PDSCH data along with the DMRS Values generated by NR_DMRS_PDSCH are then filled within a resource Grid with the help of NR_MuxOFDMSym module which is used to MUX various Physical Downlink channels. After filling the resource grid, the output is then saved to .mat file and text file and/or table using Matlab_Script and Sink respectively.

In this way, the PDSCH is generated using SystemVue.

2. PDCCH

PDCCH stands for Physical Downlink Control Channel. PDCCH is used for DCI such as downlink scheduling assignment and uplink scheduling grants.This is one of the most important channels which is supposed to be very robust and has to be easily decoded even in very harsh conditions. This is the reason why QPSK modulated data is used for PDCCH, because it is more robust than the higher order modulation schemes.

SystemVue Implementation of PDCCH:

The following block diagram shows the generation of PDCCH data using SystemVue.

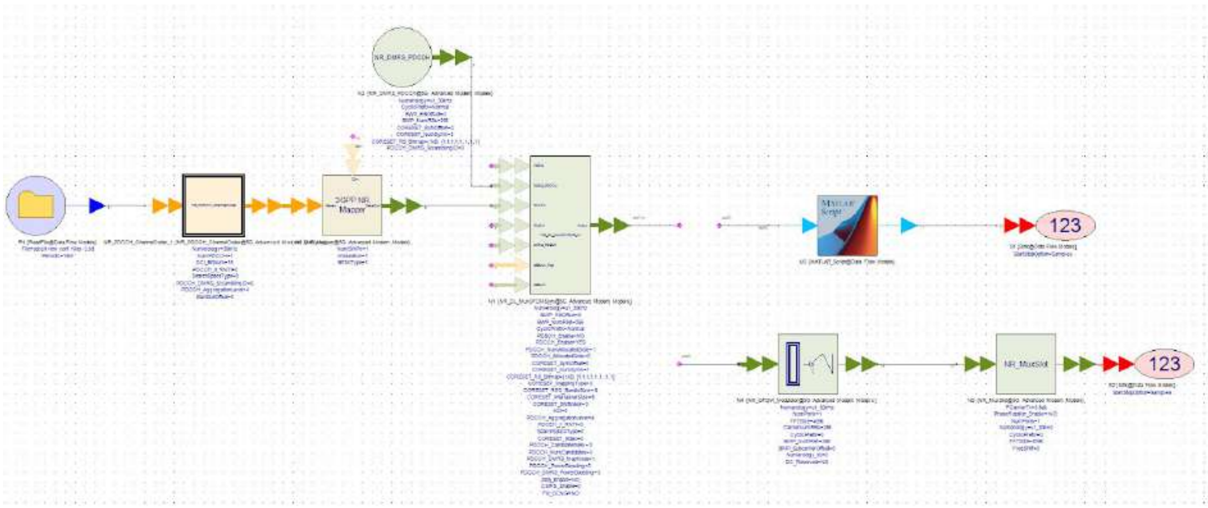

Figure 14: PDCCH generation Schematic Diagram

The following Table shows various systemvue modules which are used, their library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PDCCH_ChannelCoder	5G Advanced Modem Models	This subnetwork is used to perform whole channel coding process for PDCCH as described in 7.3 of TS 38.211

NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_DMRS_PDCCH	5G Advanced Modem Models	This model is used to generate DMRS for PDCCH
NR_DL_MuxOFDMSym	5G Advanced Modem Models	This model is responsible for multiplexing different NR downlink physical channels and physical signals to integrate them for following time-domain signal construction.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file
NR_OFDM_Modulator	5G Advanced Modem Models	This model is used to complete 3GPP NR downlink OFDM modulator.
NR_MuxSlot	5G Advanced Modem Models	This model is used to multiplex 3GPP NR downlink signal in half subframe, Cyclic Prefix is added in this module

Table 8:SystemVue Blocks for generation of PDCCH

Working: First of all the DCI (Downlink Control Information) bits are saved in a text file which is read with the help of ReadFile module. The DCI bits are the sent to NR_PDCCH_ChannelCoder module which does the whole Channel coding for the PDCCH channel. After the Channel Coding is done, the coded bits are mapped to constellation points with the help of NR_Mapper. Now the constellation points are ready to be filled inside the resource grid. NR_DMRS_PDCCH module is used to generate the DMRS values for PDCCH according to the input parameters. The DMRS values and the Data(constellation points) are now placed in the Resource Grid with the help of NR_DL_MuxOFDMSym.Now the output resource grid is saved as a .mat file and text file with the help of Matlab_Script and Sink modules respectively.

The outputs of the resource grid are also sent to NR_OFDM_Modulator to perform the IFFT and then sent to NR_MuxSlot which adds the Cyclic prefix to the IFFT output. Again the time domain output is saved as a text file with the help of the Sink module.

The following diagram shows the procedures done by NR_PDCCH_ChannelCoder:

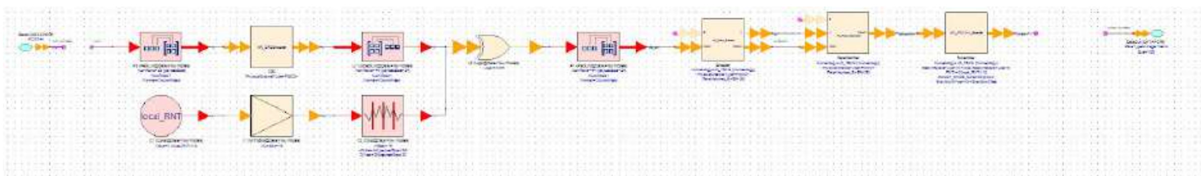

Figure 15: NR_PDCCH_ChannelCoder Submodel Schematic Diagram

First of all, CRC attachment is done with the help of NR_CRCEncoder. 24 parity bits are added with the generator polynomial as CRC_24C irrespective of the input bits size. After CRC encoding, the NR_Polar_Encoder is used to perform the Polar Coding. Polar coding is followed by Rate Matching for polar coding which is done with the help of NR_Polar_RateMatch. Finally, the NR_PDCCH_Scrambler is used to perform scrambling on PDCCH bit sequences. The cinit parameter defines the initialization value for the scrambling sequence.

3. PBCH

PBCH stands for Physical Broadcast Channel. The main purpose of PBCH is to carry(broadcast) MIB. PBCH is used for the data which is common for all users.

The following figure shows the transport block process for the PBCH :

https://www.sharetechnote.com/html/5G/image/NR_PBCH_01.png

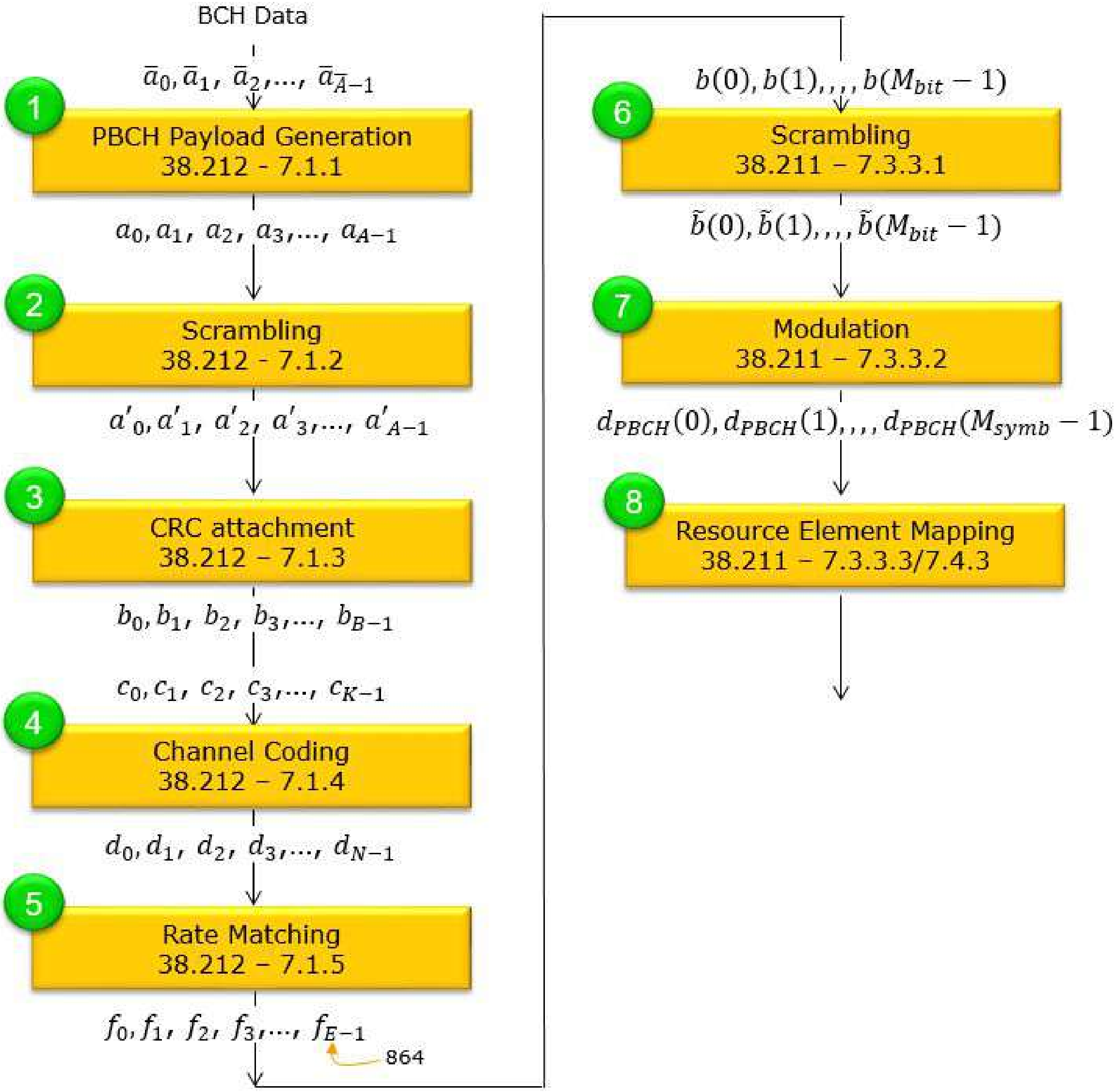

Figure 16: Transport Block Process for PBCH

SystemVue Implementation of PBCH:

The following figure shows the SystemVue implementation of PBCH

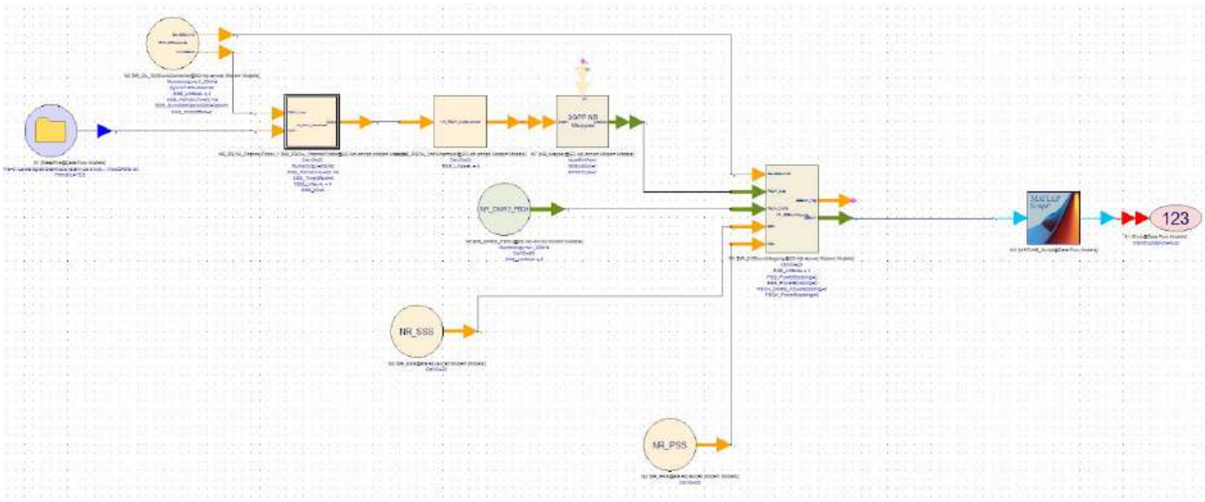

Figure 17: PBCH generation Schematic Diagram

The following table shows us various SystemVue modules used in generation of PBCH, their use and their respective libraries.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_DL_SSBlockController	5G Advanced Modem Models	This model is used to get the number of SS/PBCH blocks and the start index of SS/PBCH blocks in one slot.
NR_PBCH_ChannelCoder	5G Advanced Modem Models	This subnetwork is used to perform the whole channel coding process for PBCH channels as described in 7.1 of TS 38.212
NR_PBCH_2ndScrambler	5G Advanced Modem Models	This model is used to perform scrambling on PBCH bit sequence prior to modulation as described in 7.3.3.1 of TS 38.211
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued

		modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_DMRS_PBCH	5G Advanced Modem Models	This model is used to generate DMRS for PBCH
NR_SSS	5G Advanced Modem Models	This model is used to generate NR SSS in frequency domain
NR_PSS	5G Advanced Modem Models	This model is used to generate NR PSS in frequency domain.
NR_SSBlockMapping	5G Advanced Modem Models	This model is used to combine PSS, SSS, PBCH data and PBCH DMRS to SS/PBCH block in one slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 9:SystemVue Blocks for generation of PBCH

Working: First of all, the PBCH bits that have to be transmitted are saved in a text file. The text file is read with the help of ReadFile. The input bits are sent to NR_PBCH_ChannelCoder which is used to perform the whole channel coding. NR_DL_SSBlockController tells the channel coder how many SS/PBCH blocks will be there in one slot. After the whole channel coding process, the bits are sent to the NR_PBCH_2ndScrambler which is used to perform scrambling on PBCH bits before modulation (constellation mapping). After scrambling is done, the data is sent to NR_Mapper which is used to map the bits to the constellation points.

The module NR_DMRS_PBCH is used to generate the DMRS values for PBCH according to the given input parameters.

SSS & PSS are generated with the help of NR_SSS & NR_PSS respectively.

Now PBCH data (constellation points), DMRS, SSS and PSS mapped to the SS/PBCH block with the help of NR_SSBlockMapping.

After the mapping is done, the output is saved in the .mat files and text files with the help of Matlab_Script and Sink module respectively.

NR_PBCH_ChannelCoder:

The following figure shows the tasks done by NR_PBCH_ChannelCoder.

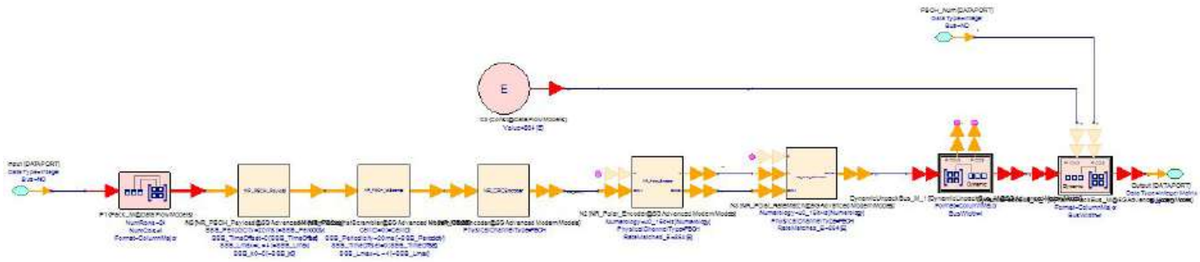

Figure 18: NR_PBCH_ChannelCoder Submodel Schematic Diagram

First of all, the input bits are taken, they are passed through the NR_PBCH_Payload which is used to generate the payload. In the payload generation, 8 bits are added to the input. The following 8 bits are added. The first four bits are the 4th , 3rd, 2nd, and 1st LSB of SFN respectively, the fifth bit is the half radio frame bit, the last three bits are the 3rd, 2nd, and 1st LSB of SS/PBCH block index respectively. After adding the payload bits addition, the first scrambling is done on the PBCH data with the help of NR_PBCH_1stScrambler. This is followed by NR_CRCEncoder which is used to perform the CRC addition on the data. For PBCH the CRC is always CRC_24C. After CRC encoding, NR_Polar_Encoder is used to perform the Polar Coding. Finally, the Rate Matching for Polar Code is done with the help of NR_Polar_RateMatch.

CHAPTER 4

UPLINK PHYSICAL SIGNALS

According to 3GPP TS 38.211 (v 15.8.0), Uplink Consists of one kind of Physical Signal i.e. Reference Signals.

Uplink Reference Signals are of 4 kinds, these are listed below:

- DMRS for PUSCH
- DMRS for PUCCH
- PTRS for PUSCH
- SRS

1. DMRS for PUSCH

DM-RS is used for channel estimation as part of coherent demodulation of PUSCH. PUSCH DMRS is a special type of physical layer signal which functions as a reference signal for decoding PUSCH.

SystemVue Implementation of DMRS for PUSCH:

The following diagram shows the implementation of DMRS for PUSCH in SystemVue.

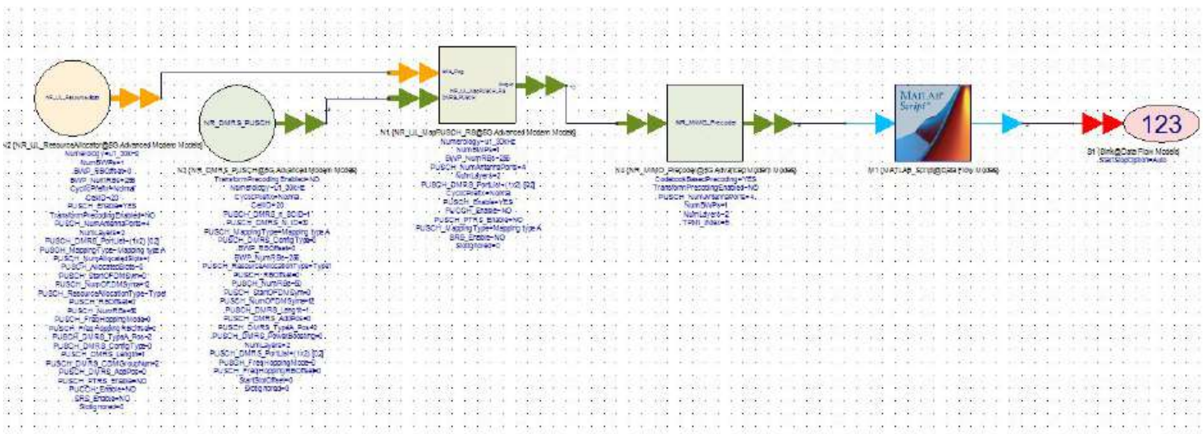

Figure 19: DMRS for PUSCH generation Schematic Diagram

The following table shows the various SystemVue modules, their libraries and their use.

SystemVue Module	Library	Use

NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_DMRS_PUSCH	5G Advanced Modem Models	This model is used to generate sequence of DMRS for PUSCH in one slot which is described in subclause 6.4.1.1.1 of TS 38.211
NR_UL_MapPUSCH_RS	5G Advanced Modem Models	This module is used to map PUSCH DMRS onto its BWP's physical resource grid.
NR_MIMO_Precoder	5G Advanced Modem Models	This model performs MIMO precoding as described in 6.3.1.5 of TS 38.211
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 10: SystemVue Blocks for generation of PUSCH

Working: First of all, NR_DMRS_PUSCH is used to generate the DMRS sequence for PUSCH according to the given parameters. Now these DMRS values are sent to NR_UL_MapPUSCH_RS which is used to map the DMRS values to the Resource Grid. The locations of DMRS are given by NR_UL_ResourceAllocator. With the help of these locations, Resource Grid is generated.Now the Output Resource Grid is sent to NR_MIMO_Precoder which is used to do the MIMO precoding. Finally the output is saved in the form of .mat file and text file with the help of Matlab_Script and Sink respectively.

2. SRS

SRS stands for Sounding Reference Signal. High level concept of NR SRS is the same as in LTE SRS and some of the lower level parameters are very similar to LTE SRS lower layer parameters. The Sounding Reference Signal (SRS) is a reference signal transmitted by the UE in the uplink direction which is used by the eNodeB to estimate the uplink channel quality over a wider bandwidth. The eNodeB may use this information for uplink frequency selective scheduling.The eNodeB can also use SRS for uplink timing estimation as part of timing alignment procedure, particularly in situations like there are no PUSCH/PUCCH transmissions occurring in the uplink for a long time in which case, the eNodeB relies on SRS for uplink timing estimation.

SystemVue Implementation of SRS:

The following Figure shows the SystemVue implementation of SRS.

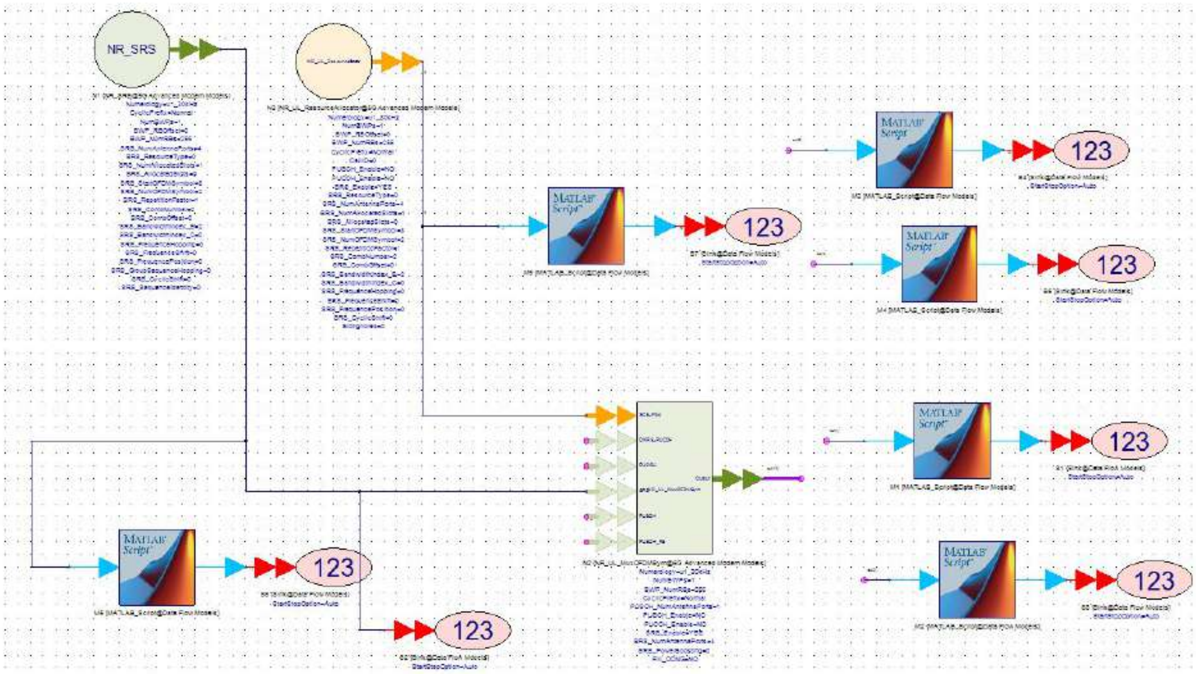

Figure 20: SRS generation Schematic Diagram

The following table shows various SystemVue modules used in SRS generation, their libraries and their use.

SystemVue Module	Library	Use

NR_SRS	5G Advanced Modem Models	This model is used to generate SRS as described in 6.4.1.4.2 of TS 38.211
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 11:SystemVue Blocks for generation of SRS

Working: First of all, NR_SRS is used to generate the SRS values according to the given input parameters. NR_UL_ResourceAllocator tells about the locations of SRS in the Resource grid. Now with the help of both Values and locations, the grid is generated by the NR_UL_MuxOFDMSym. Now the Resource grid is saved to a .mat file and text file with the help of Matlab_Script and Sink module.

The NR_UL_ResourceAllocator uses the following Channel type indicator to tell about the locations to NR_UL_MuxOFDMSym. For SRS ‘1300’ is used as a channel indicator.

EMPTY	0
NO_TRANSMIT	320
PUCCH	1005
PUCCH_DMRS	1006
DMRS_PREOCCUPY	322
PUSCH	1007
PUSCH_DMRS	113
PTRS	513
PTRS_PREOCCUPY	500
SRS	1300
SRS_PREOCCUPY	1355

Figure 21: Channel Indicator

3. DMRS for PUCCH

PUCCH DMRS is a special type of physical layer signal which functions as a reference signal for decoding PUCCH.

PUCCH DMRS is of 4 types which are PUCCH DMRS format1 , format2 , format 3 and format 4.

SystemVue implementation of PUCCH DMRS format 1:

The following figure shows the SystemVue schematic for generation of PUCCH DMRS format 1.

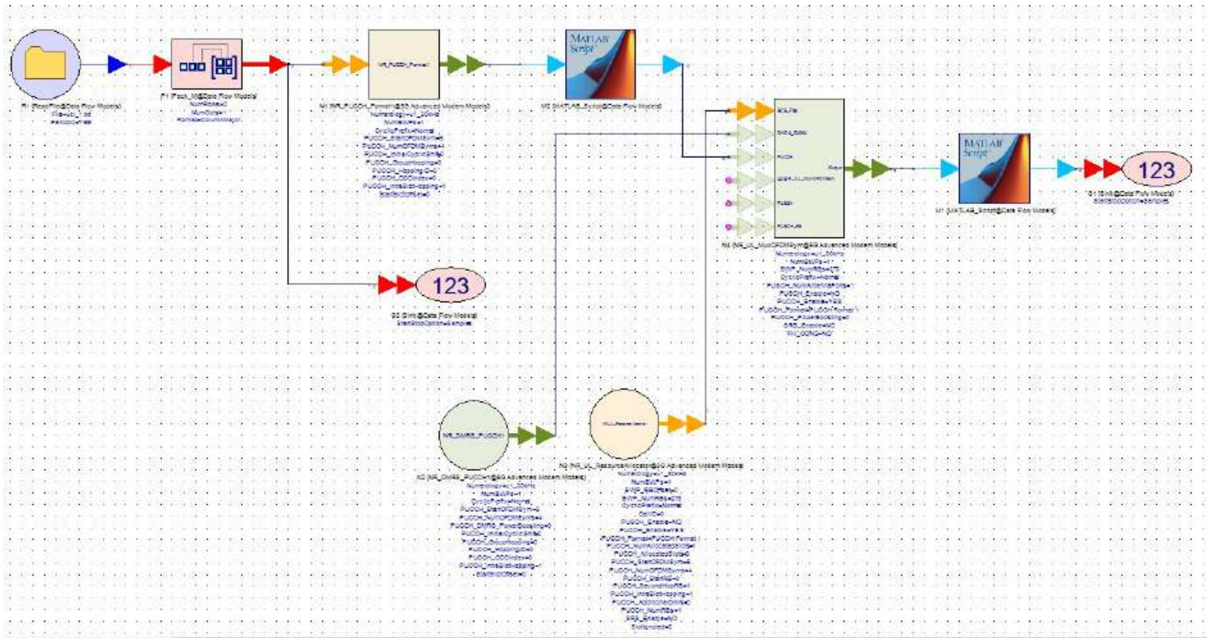

Figure 22: PUCCH DMRS Format 1 generation Schematic Diagram

The following table shows various SystemVue modules required, their respective library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
Pack_M	Data Flow Models	This model packs NumRows · NumCols input scalar values into an output matrix with NumRows and NumCols.
NR_PUCCH_Format1	5G Advanced Modem Models	This model is used to generate PUCCH format1 sequence according to the input bits as described in 6.3.2.4.1 of TS 38.211.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input

		data and produce output data
NR_DMRS_PUCCH1	5G Advanced Modem Models	This model is used to generate DMRS for PUCCH format1 as described in 6.4.1.3.1.1 of TS 38.211
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 12: SystemVue Blocks for generation of DMRS for PUCCH format1

Working: As we want to fill in the Resource grid with only DMRS, we can do this by substituting the PUCCH data with zeros. First we take random UCI bits as input. Then they are passed from Pack_M which reshapes them and sent to the NR_PUCCH_Format1 which is used to convert the bits to PUCCH format 1 sequence. Now the PUCCH format1 sequence is ready to be filled within the Resource Grid. Now we replace the PUCCH sequence with zeros with the help of Matlab_script module.

The DMRS values are generated with the help of NR_DMRS_PUCCH1 and the locations are given by NR_UL_ResourceAllocator. For PUCCH DMRS '1006' is used as a channel indicator. Now the NR_UL_MuxOFDMSym fills in the DMRS values in the resource grid.

The output is saved as a .mat file and/or text file with the help of Matlab_Script and Sink module respectively.

SystemVue Implementation of PUCCH DMRS format 2

The following figure shows the SystemVue schematic for generation of PUCCH DMRS format 2.

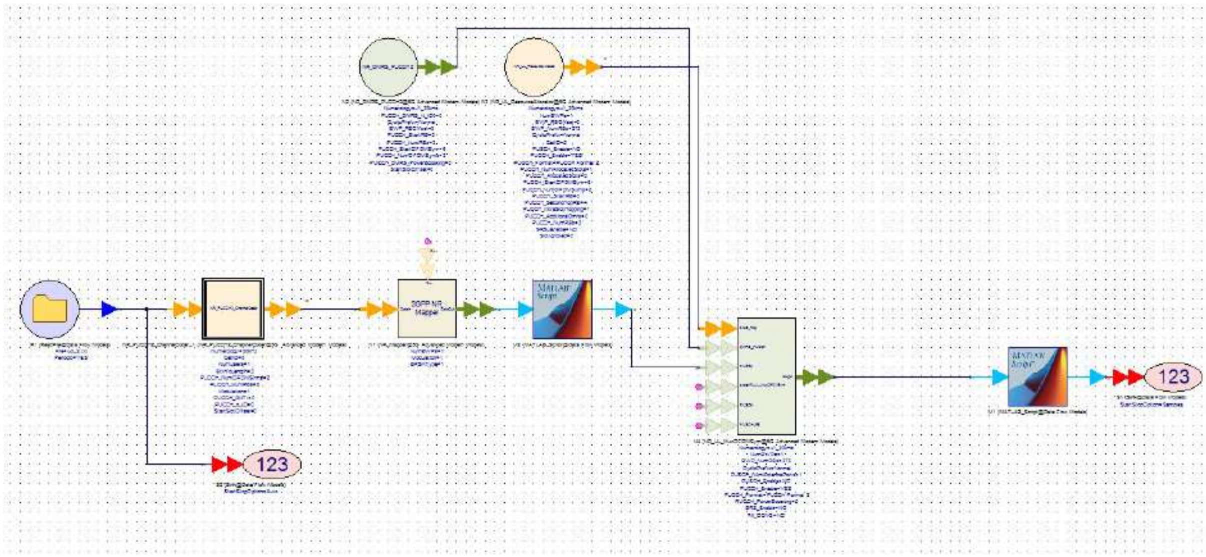

Figure 23: PUCCH DMRS Format 2 generation Schematic Diagram

The following table shows various SystemVue modules required, their respective library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PUCCH2_ChannelCoder	5G Advanced Modem Models	This subnetwork is used to perform the whole channel coding process for PUCCH Format 2 as described in 6.3.1 of TS 38.211.
NR_Mapper	5G Advanced	This model takes binary

	Modem Models	digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
NR_DMRS_PUCCH2	5G Advanced Modem Models	This model is used to generate a sequence of DMRS for PUCCH format2 in one slot.
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 13: SystemVue Blocks for generation of DMRS for PUCCH format2

Working: First of all, random UCI bits are taken as input using the ReadFile module. Now the whole channel coding process is done with the help of NR_PUCCH2_ChannelCoder. After the channel coding, the bits are sent to NR_Mapper for being mapped to the constellation points. After mapping to the constellation points, the constellation points are sent to zero so as to fill the Resource Grid with only the DMRS values.

The DMRS values are generated by the NR_DMRS_PUCCH2 module and the locations are indicated by NR_UL_ResourceAllocator module. Now with the help of both locations and Values of DMRS, the Resource Gris is generated by NR_UL_MuxOFDMSym module. Finally the output Resource Grid is saved as a .mat file and a text file with the help of Matlab_Script and Sink Module.

SystemVue Implementation of PUCCH DMRS format 3

The following figure shows the SystemVue schematic for generation of PUCCH DMRS format 3.

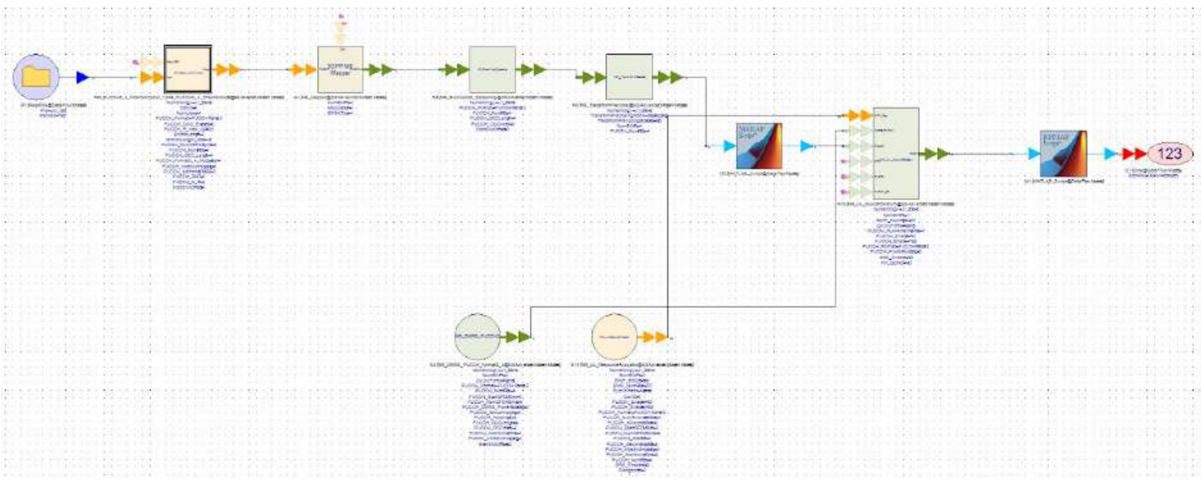

Figure 24: PUCCH DMRS Format 3 generation Schematic Diagram

The following table shows various SystemVue modules required, their respective library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PUCCH3_4_ChannelCoder	5G Advanced Modem Models	The subnet is used to perform the whole channel coding process

		for PUCCH Format 3/4 as described in 6.3.1 of TS 38.212
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_Blockwise_Spreading	5G Advanced Modem Models	This model is used to perform Block-wise spreading on PUCCH as described in 6.3.2.6.3 of TS 38.211.
NR_TransformPrecoder	5G Advanced Modem Models	This model is used to perform transform precoding as described in 6.3.1.4 of TS 38.211.
Matlab_script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
NR_DMRS_PUCCH_Format3_4	5G Advanced Modem Models	This model is used to generate DMRS for PUCCH format3 and PUCCH format4 as described in 6.4.1.3.3.1 of TS 38.211
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference

		signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 14: SystemVue Blocks for generation of DMRS for PUCCH format3

Working: First of all, random UCI bits are taken as input, then they are passed from NR_PUCCH3_4_ChannelCoder which is used to perform the Channel Coding for format 3. After the channel coding, Mapping is done to constellation points with the help of NR_Mapper. After mapping to the constellation points, Blockwise spreading on PUCCH is done with the NR_Blockwise_Spreading followed by NR_TransformPrecoder which is used to perform the Transform Precoding. After transform precoding, the PUCCH data is set to zero with the help of Matlab_Script.

NR_DMRS_PUCCH_Format3_4 is used to generate the PUCCH Format 3 DMRS values and the location of DMRS PUCCH is indicated with the help of NR_UL_ResourceAllocator. Now the Resource Grid is filled in with the DMRS values at correct locations.

The output resource grid is saved to a .mat file and text file with the help of Matlab_Script and Sink Module.

SystemVue Implementation of PUCCH DMRS format 4

The following figure shows the SystemVue schematic for generation of PUCCH DMRS format 4.

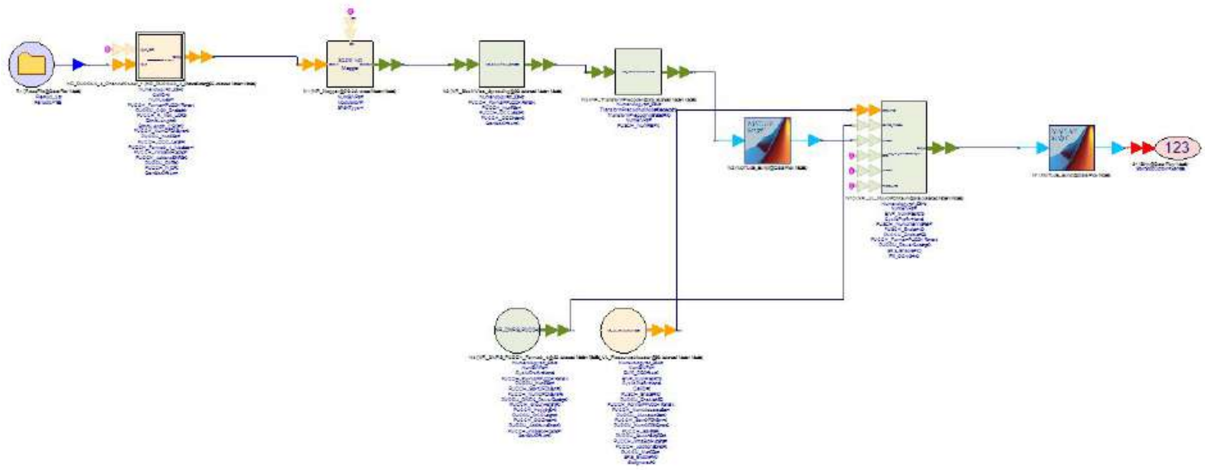

Figure 25: PUCCH DMRS Format 4 generation Schematic Diagram

The table for the various SystemVue modules is the same as that of DMRS for PUCCH Format 3.

Working: First of all, the random bits are taken as input then passed through NR_PUCCH3_4_ChannelCoder, NR_Mapper, NR_Blockwise_Spreading, NR_TransformPrecoder . After passing through the NR_TransformPrecoder, the symbols are sent through the Matlab_Script which is used to replace the PUCCH format 4 data to zeros.

NR_DMRS_PUCCH_Format3_4 is used to generate the DMRS values for PUCCH format 4. The locations of the DMRS are given by NR_UL_ResourceAllocator. Now the locations and the values of DMRS are fed to the NR_UL_MuxOFDMSym which is used to generate the grid. Now the output grid is saved as a .mat file and a text file with the help of Matlab_Script and Sink modules respectively.

CHAPTER 5

UPLINK PHYSICAL CHANNELS

According to 3GPP TS 38.211, Uplink is having three different kinds of Physical Channels, these are

- PUSCH
- PUCCH
- PRACH

1. PUSCH

PUSCH stands for Physical Uplink Channel. PUSCH is the Physical channel that carries user data. PUSCH can also be used for carrying the UCI also (optional).

SystemVue Implementation of PUSCH

The following figure shows the SystemVue schematic for generation of PUSCH.

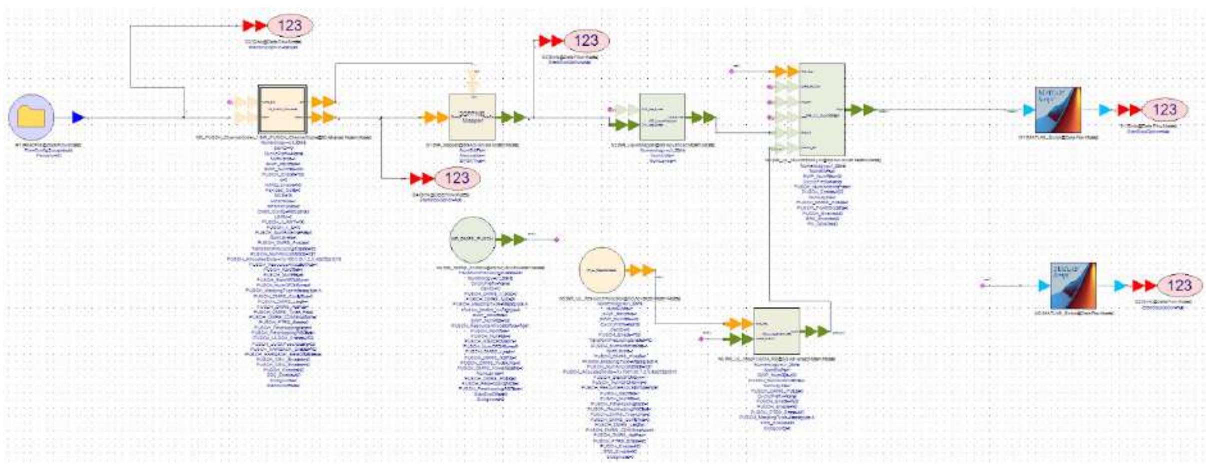

Figure 26: PUSCH generation Schematic Diagram

The following table shows various SystemVue modules used in generation of PUSCH generation, their library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII

		text from the file named by the File parameter.
NR_PUSCH_ChannelCoder	5G Advanced Modem Models	This subnet is used to perform the whole channel coding process for PUSCH as described in 6.2 of TS 38.211 .
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS 38.211
NR_LayerMapper	5G Advanced Modem Models	This model is used for layer mapping on PUSCH as described in 6.3.1.3 of TS 38.211 .
NR_DMRS_PUSCH	5G Advanced Modem Models	This model is used to generate sequence of DMRS for PUSCH in one slot which is described in subclause 6.4.1.1.1 of TS 38.211
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MapPUSCH_RS	5G Advanced Modem Models	This module is used to map PUSCH DMRS onto its BWP's physical resource grid
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency

		resource grid in one OFDM slot
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 15: SystemVue Blocks for generation of PUSCH

Working: First of all, the input bits are saved to a text file which is read with the help of ReadFile Module. Now these input bits are sent to NR_PUSCH_ChannelCoder which performs the whole channel coding process. After that the coded bits are sent to NR_Mapper which is used to map the bits to the constellation points. Now the constellations are sent to NR_LayerMapper for layer mapping on the PUSCH data. Now the PUSCH data is ready to be filled within the resource grid.

NR_DMRS_PUSCH is used to generate the DMRS values for the PUSCH according to the given input parameters.

NR_UL_ResourceAllocator provides the locations at which the DMRS and the PUSCH data will be filled within the resource grid. NR_UL_MapPUSCH_RS is then used to generate the DMRS Resource Grid . Now with the help of NR_UL_ResourceAllocator, DMRS Resource Grid and PUSCH data, the final Resource Grid is generated by NR_UL_MuxOFDMSym.

Now the Resource Grid is saved as a .mat file and text file with the help of Matlab_Script and Sink Module respectively.

NR_PUSCH_ChannelCoder:

The following operations are done by NR_PUSCH_ChannelCoder.

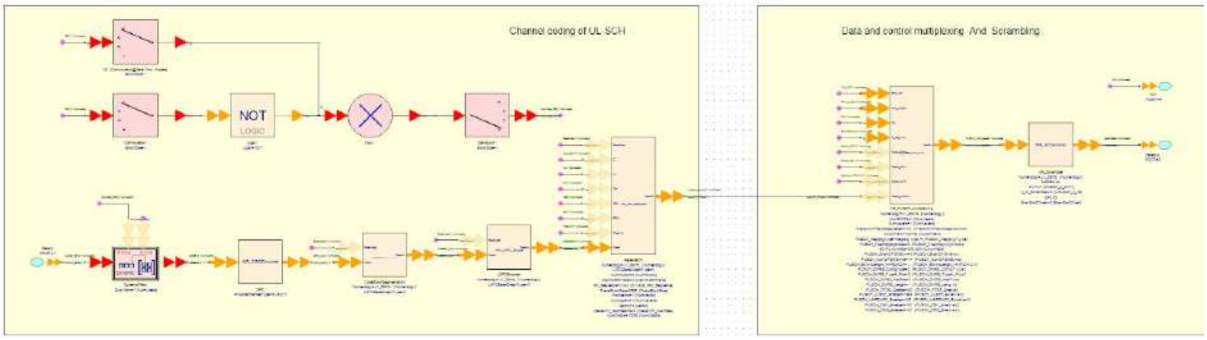

Figure 27: NR_PUSCH_ChannelCoder Submodel Schematic Diagram

First of all, the input bits are taken and CRC attachment is done with the help of NR_CRCEncoder. For PUSCH, if the Transport Block size > 3824 then 24 parity bits are added, otherwise 16 parity bits are added. If Transport Block Size > 3824, then the CRC type is CRC_24A, otherwise the CRC type is CRC_16. After the CRC encoding is done, NR_LDPC_CodeBlockSegmentation is used to perform code block segmentation on transport blocks that use LDPC coders. This model supports both LDPC base graph type 1 and base graph type 2. After the Code Block Segmentation is done, LDPC coding is done with the help of NR_LDPC_Encoder. This is followed by NR_LDPC_RateMatch module which is used to perform the rate matching for LDPC coding. After the Rate Matching, the data and control multiplexing is done with the help of NR_PUSCH_Multiplexing. Finally the Uplink Scrambling is done with the help of NR_Scrambler. The scrambling sequence generator shall be initialized with the RNTI and n_ID_Scramber parameters.

2. PUCCH

PUCCH stands for Physical Uplink Control Channel. PUCCH is mainly used to convey UCI(Uplink Control Information). PUCCH is also used for the sending HARQ-ACK, Scheduling Request, CSI reports (CQI, PMI, RI, LI and beam related info.).

According to 3GPP TS 38.211, Table 6.3.2.1-1 tells us about various PUCCH formats.

PUCCH format	Length in OFDM symbols $N_{\mathrm{symb}}^{\mathrm{PUCCH}}$	Number of bits
0	1 – 2	≤2
1	4 – 14	≤2
2	1 – 2	>2
3	4 – 14	>2
4	4 – 14	>2

Figure 28: Table 6.3.2.1-1 PUCCH formats

All of the PUCCH formats are implemented in SystemVue.

PUCCH format 0:

The following figure shows the SystemVue implementation of PUCCH Format 0.

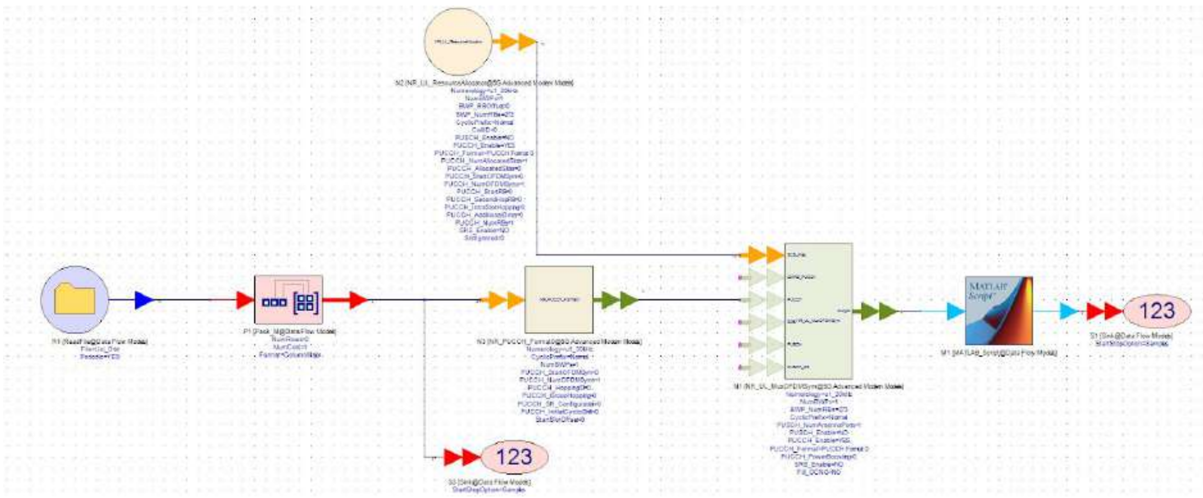

Figure 29: PUCCH Format 0 Generation Schematic Diagram

The following table shows us various SystemVue modules which are used in PUCCH Format 0 generation , their library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
Pack_M	Data Flow Models	This model packs NumRows · NumCols input scalar

		values into an output matrix with NumRows and NumCols
NR_PUCCH_Format0	5G Advanced Modem Models	This model is used to generate PUCCH format0 sequence according to the input bits as described in 6.3.2.3.1 of TS 38.211 .
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot.
NR_UL_ResourceGrid	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 16: SystemVue Blocks for generation of PUCCH format 0

Working: First of all the UCI (Uplink Control Information) bits are taken as input. Then the reshape of the bits are done with the help of the Pack_M module. Now the input bits are fed to NR_PUCCH_Format0 which is used to generate the PUCCH format 0 sequence according to the given input bits. NR_UL_ResourceAllocator is used to provide the information about the locations of PUCCH Format 0. For Format 0, there is no DMRS. Now with the help of the values and locations of the PUCCH Format 0 sequence, the Resource Grid is generated by the NR_UL_MuxOFDMSym module. This resource grid is then saved as a .mat file and text file with the help of Matlab_Script and Sink module respectively.

PUCCH Format 1:

The following figure shows the SystemVue implementation of PUCCH Format 1.

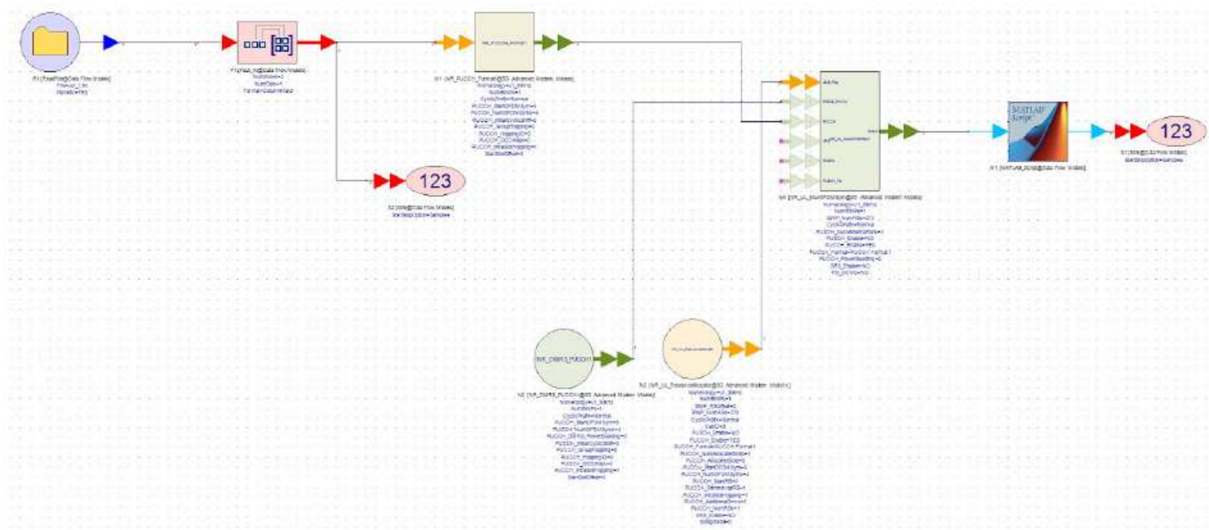

Figure 30: PUCCH Format 1 Generation Schematic Diagram

The following table shows us various SystemVue modules which are used in PUCCH Format 1 generation , their library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
Pack_M	Data Flow Models	This model packs NumRows · NumCols input scalar values into an output matrix with NumRows and NumCols
NR_PUCCH_Format1	5G Advanced Modem Models	This model is used to generate PUCCH format1 sequence according to the input bits as described in 6.3.2.4.1 of TS 38.211

NR_DMRS_PUCCH1	5G Advanced Modem Models	This model is used to generate DMRS for PUCCH format1 as described in 6.4.1.3.1.1 of TS 38.211
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 17: SystemVue Blocks for generation of PUCCH format 1

Working: First of all the UCI bits are taken as an input with the help of ReadFile module. Now the bits are reshaped with the help of the Pack_M module. Now the reshaped input bits are sent to NR_PUCCH_Format1 which is used to generate the PUCCH Format 1 sequence according to the given bits. NR_DMRS_PUCCH1 is used to generate the DMRS values for PUCCH Format 1. NR_UL_ResourceAllocator is used to tell the locations of DMRS and PUCCH Format 1 values. Now with the help of the DMRS values, PUCCH Format 1 values and the locations of both PUCCH and DMRS, the module NR_UL_MuxOFDMSym generates the Resource Grid. The Resource Grid is then saved to .mat file and text file with the help of Matlab_Script and Sink modules respectively.

PUCCH Format 2:

The following figure shows the SystemVue implementation of PUCCH Format 2.

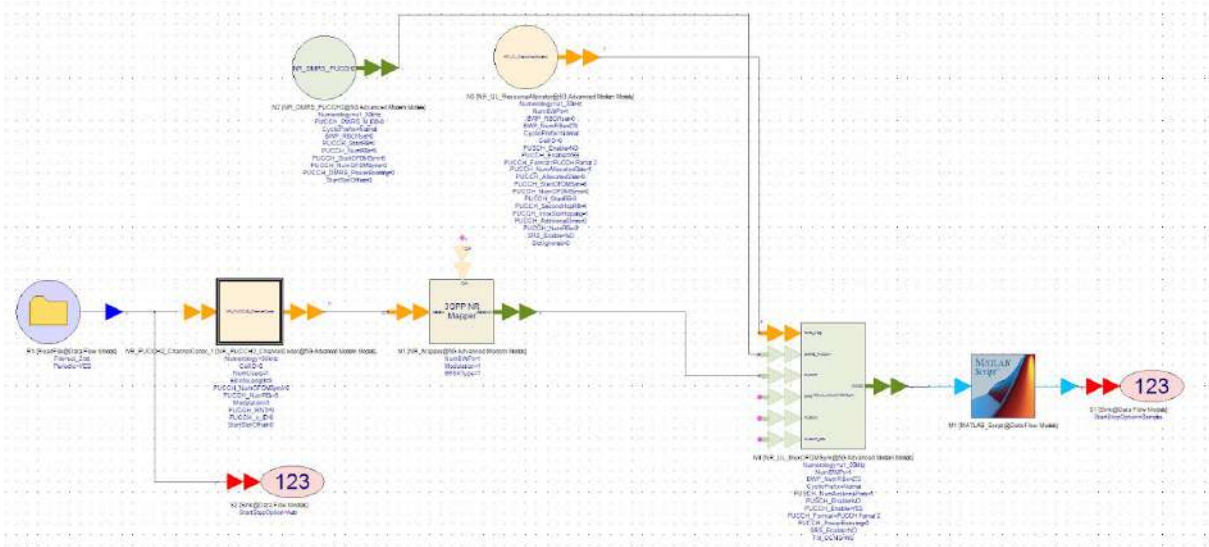

Figure 31: PUCCH Format 2 Generation Schematic Diagram

The following table shows us various SystemVue modules which are used in PUCCH Format 2 generation , their library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PUCCH2_ChannelCoder	5G Advanced Modem Models	This subnetwork is used to perform the whole channel coding process for PUCCH Format 2 as described in 6.3.1 of TS 38.211.
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS

		38.211
NR_DMRS_PUCCH2	5G Advanced Modem Models	This model is used to generate a sequence of DMRS for PUCCH format2 in one slot
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 18: SystemVue Blocks for generation of PUCCH format 2

Working: First of all, the UCI bits are taken as input with the help of the ReadFile module. Now the input bits are sent to NR_PUCCH2_ChannelCoder which is used to perform the whole channel coding for PUCCH Format 2. After that, the coded bits are sent to the NR_Mapper module which is used to map the bits to the constellation points. NR_DMRS_PUCCH2 is used to generate the DMRS values for PUCCH format 2 . NR_ResourceAllocator is used to indicate the values of both DMRS and PUCCH data. Now the module NR_UL_MuxOFDMSym is used to generate the Resource Grid with the help of the PUCCH data, DMRS and their locations. Now the Resource Grid is saved to the .mat file and the text file with the help of Matlab_Script and Sink module.

PUCCH Format 3:

The following figure shows the SystemVue implementation of PUCCH Format 3.

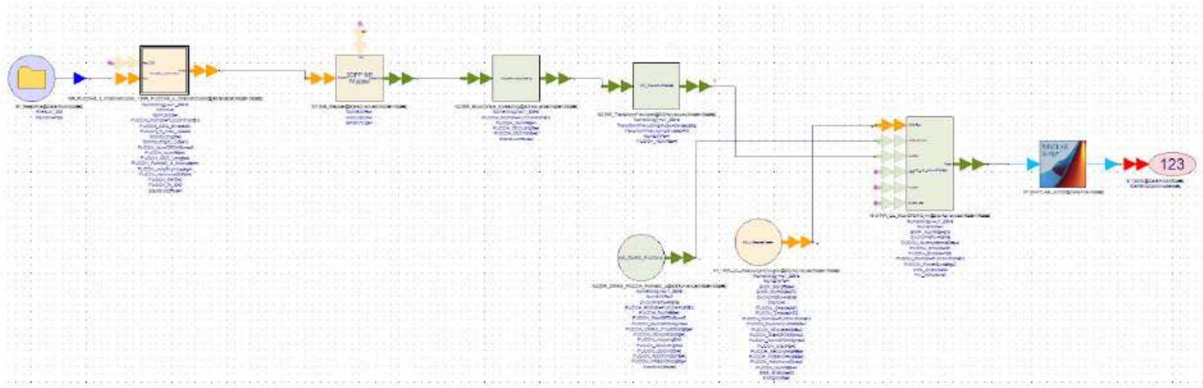

Figure 32: PUCCH Format 3 Generation Schematic Diagram

The following table shows us various SystemVue modules which are used in PUCCH Format 3 generation , their library and their use.

SystemVue Module	Library	Use
ReadFile	Data Flow Models	This model reads floating point (real) values in ASCII text from the file named by the File parameter.
NR_PUCCH3_4ChannelCoder	5G Advanced Modem Models	The subnet is used to perform the whole channel coding process for PUCCH Format 3/4 as described in 6.3.1 of TS 38.212.
NR_Mapper	5G Advanced Modem Models	This model takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, x=I+jQ, as output, as described in 5.1 of TS

		38.211
NR_Blockwise_Spreading	5G Advanced Modem Models	This model is used to perform Block-wise spreading on PUCCH as described in 6.3.2.6.3 of TS 38.211.
NR_TransformPrecoder	5G Advanced Modem Models	This model is used to perform transform precoding as described in 6.3.1.4 of TS 38.211.
NR_DMRS_PUCCH_Format3_4	5G Advanced Modem Models	This model is used to generate DMRS for PUCCH format3 and PUCCH format4 as described in 6.4.1.3.3.1 of TS 38.211
NR_UL_ResourceAllocator	5G Advanced Modem Models	This model is responsible for generating flags to indicate resource elements allocation with respect to all possible physical channels and physical signals
NR_UL_MuxOFDMSym	5G Advanced Modem Models	This model is used to constitute 5G NR uplink OFDM Symbol. It multiplexes PUSCH, PUCCH, and reference signals(DMRS for PUSCH, DMRS for PUCCH and SRS) onto the frequency resource grid in one OFDM slot.
Matlab_Script	Data Flow Models	This model uses MATLAB Script equations to process input data and produce output data
Sink	Data Flow Models	This model is used to capture the data and can be used to load it to a table, graph and text file

Table 19: SystemVue Blocks for generation of PUCCH format 3

Working: First of all, the UCI bits are taken as input with the help of the ReadFile module . Now the bits are sent to NR_PUCCH3_4ChannelCoder which performs the whole channel coding. After the channel coding, the coded bits are mapped to constellation points by NR_Mapper module. NR_Mapper is followed by NR_Blockwise_Spreading which is used to perform the Blockwise Spreading for PUCCH. After the Block Wise Spreading, NR_TransformPrecoder is used to perform the Transform Precoding. After the precoding, the PUCCH data is ready to be filled inside the Resource Grid. NR_DMRS_PUCCH_Format3_4 is used to generate the DMRS values for PUCCH format 3. NR_UL_ResourceAllocator is used to specify the locations of PUCCH and DMRS data. Now the resource grid is formed by NR_UL_MuxOFDMSym with the help of DMRS , PUCCH and their locations. Now the Resource Grid is saved as a .mat file and text file with the help of Matlab_Script and Sink modules respectively.

PUCCH Format 4:

The following figure shows the SystemVue implementation of PUCCH Format 4.

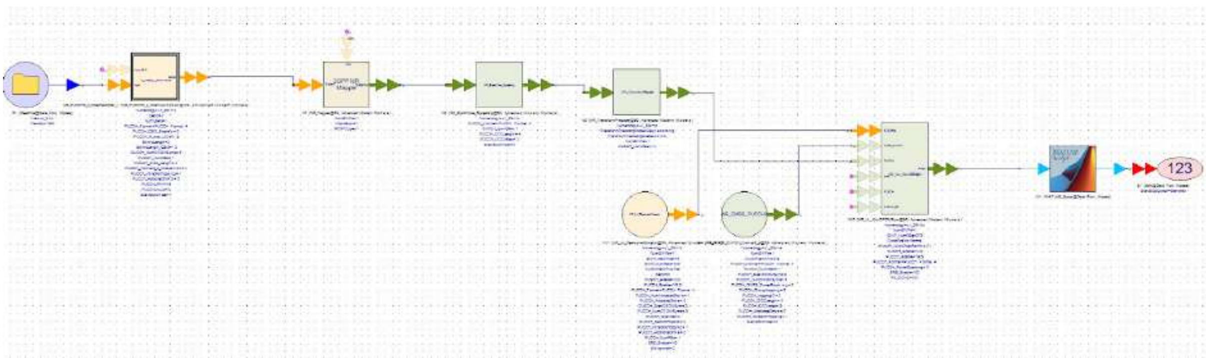

Figure 33: PUCCH Format 4 Generation Schematic Diagram

The table for the various SystemVue modules is the same as that of PUCCH Format 3.

Working: First of all the UCI bits are saved to a text file . The UCI bits are then read with the help of the ReadFile module. The bits are sent to NR_PUCCH3_4ChannelCoder which is used to perform the whole channel coding process for PUCCH Format 4. Now the Coded bits are sent to NR_Mapper which converts the bits to Constellation points. This is followed by NR_BlockWise_Spreading which is used to perform the Block Wise spreading on PUCCH. The symbols are then sent to NR_Transformprecoder . Now the constellation points are ready to be mapped inside the resource grid. NR_DMRS_PUCCH_Format3_4 is used to generate the DMRS data for PUCCH format 4. The locations of both are indicated by NR_UL_ResourceAllocator. Now NR_UL_MuxOFDMSym is used to generate the Resource Grid . Now the Resource Grid is saved as a .mat file, text file with the help of Matlab_Script and Sink module.

CHAPTER 6

PHYSICAL CHANNELS IMPLEMENTATION USING SIGNAL STUDIO

Keysight's Signal Studio Pro is used for testing for various Physical Channels and Signals in 5G NR. It can also be used for testing the hardware. The output waveforms can be downloaded to various Keysights Instruments.

This section provides implementation of various channels and signals using the Keysight Signal Studio pro.

1. PDSCH

The following figures show the PDSCH implementation.

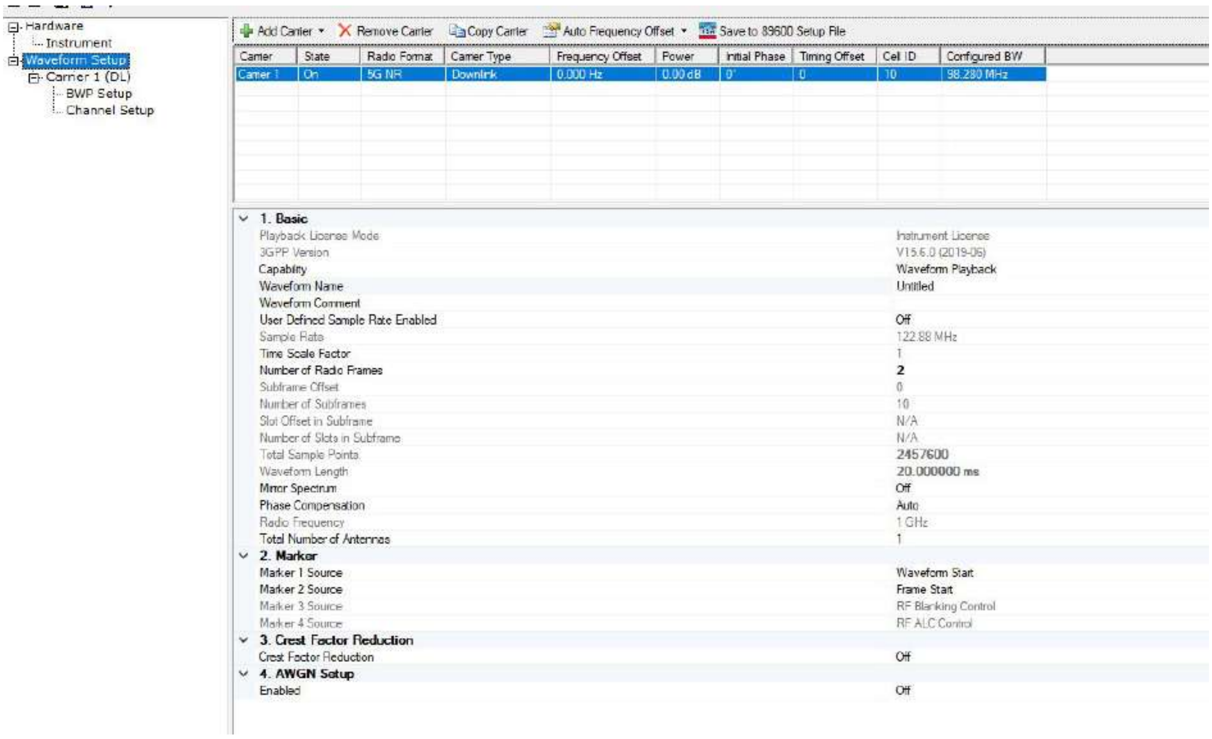

Figure 34:PDSCH input parameters

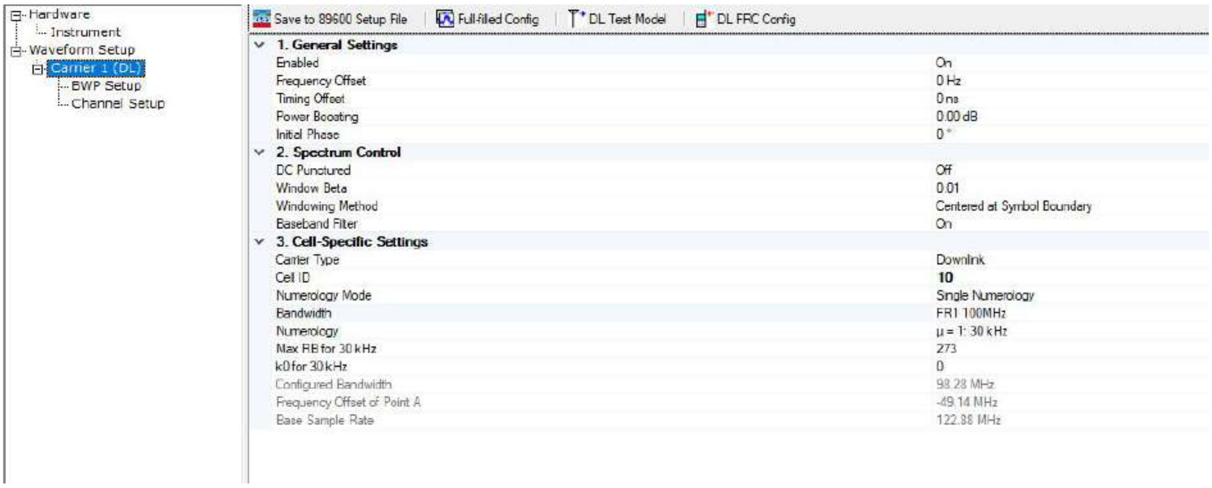

Figure 34.a :PDSCH input parameters

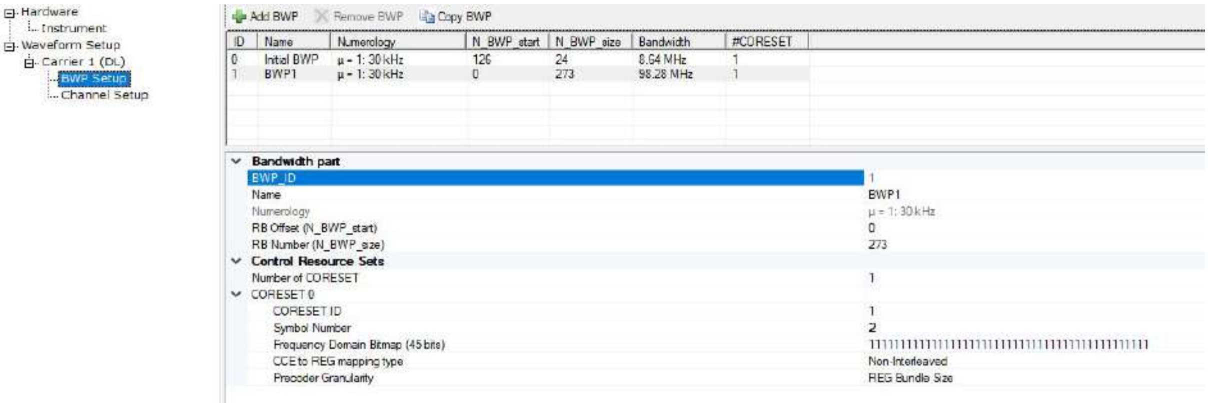

Figure 34.b :PDSCH input parameter

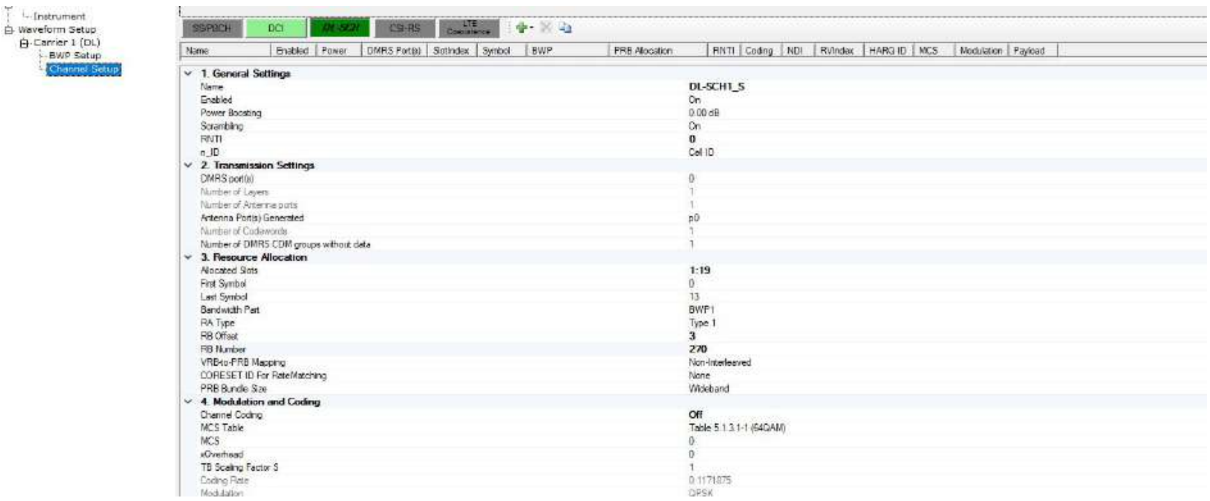

Figure 34.c :PDSCH input parameters

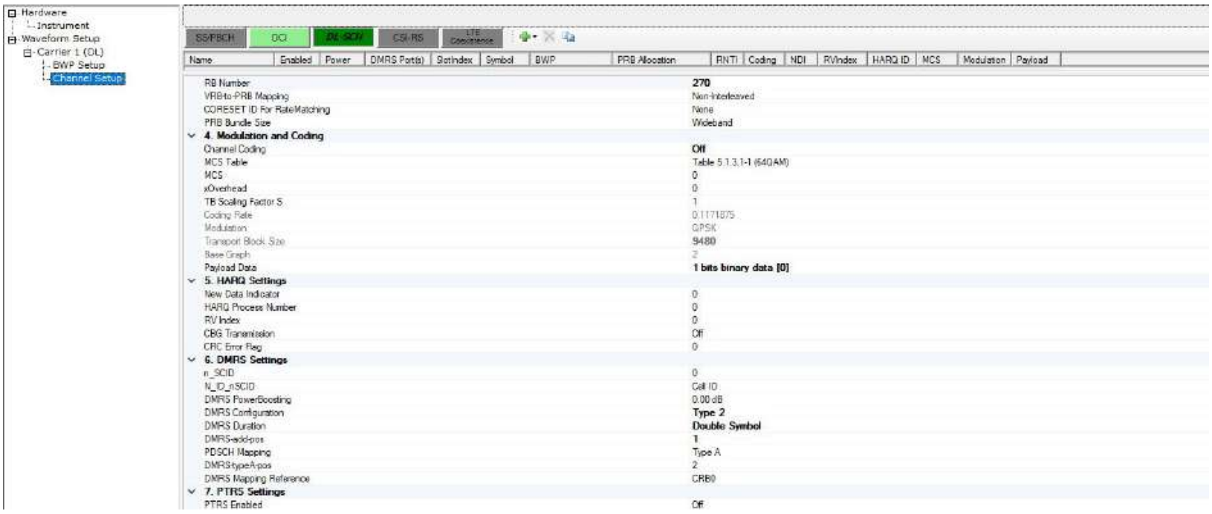

Figure 34.d :PDSCH input parameters

The above figures show the various input configurations for the PDSCH in Signal Studio Pro.

According to the various input parameters, the following figures show the various outputs generated for the PDSCH.

The ChannelAllocation and the Spectrum have been plotted for PDSCH.

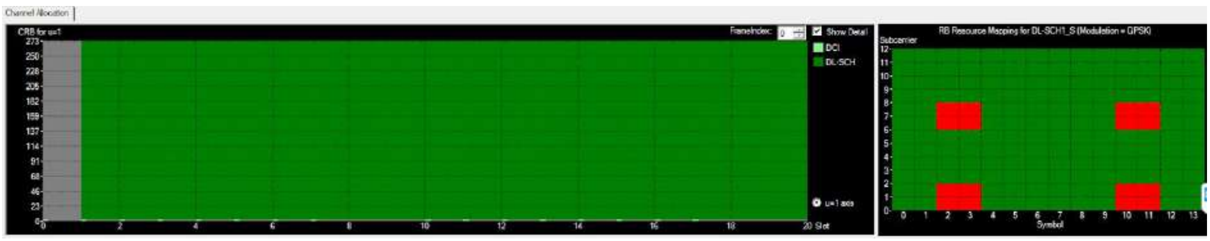

Figure 35:PDSCH Channel Allocation Output

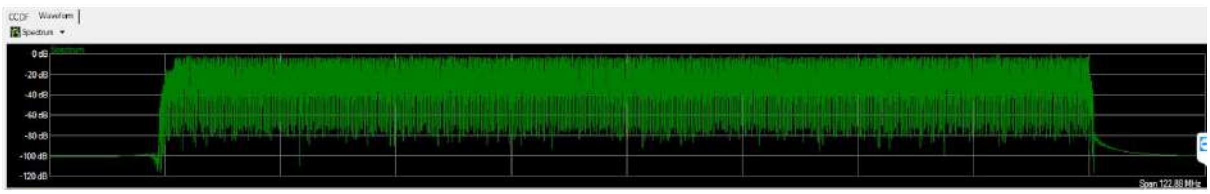

Figure 35.a :PDSCH Spectrum

2. PDCCH

The following figures show the PDCCH (DCI) channel implementation in Signal Studio Pro.

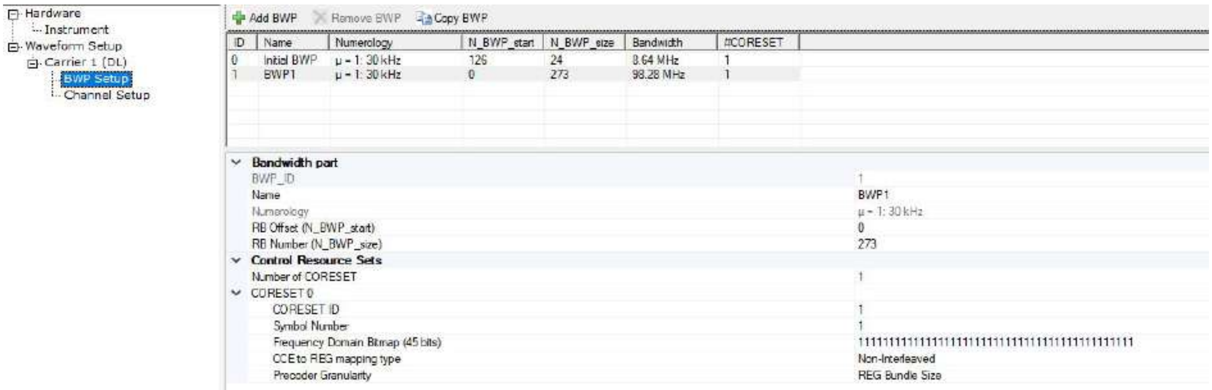

Figure 36 :PDCCH input parameters

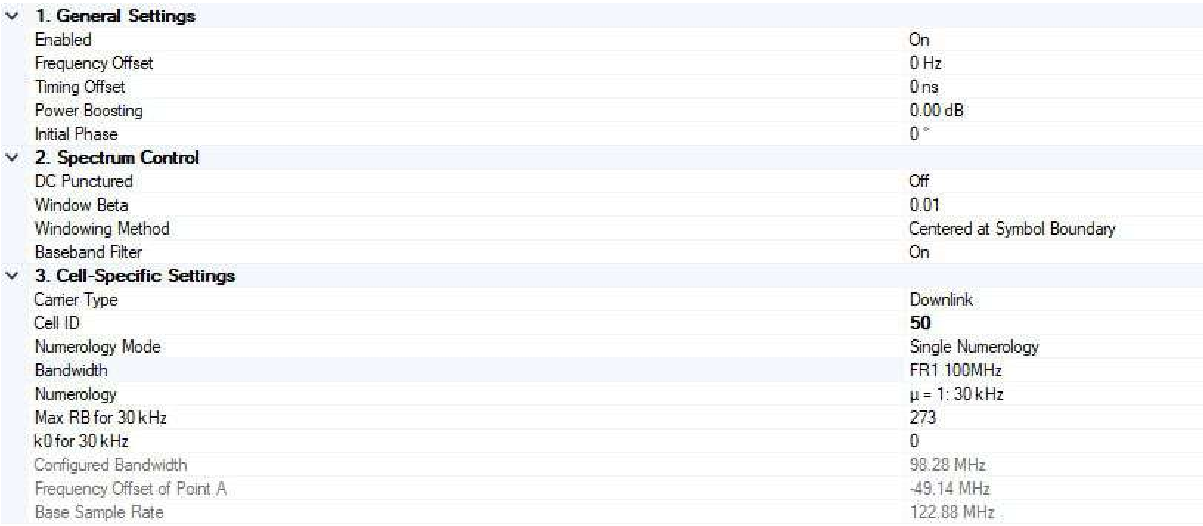

Figure 36.a :PDCCH input parameters

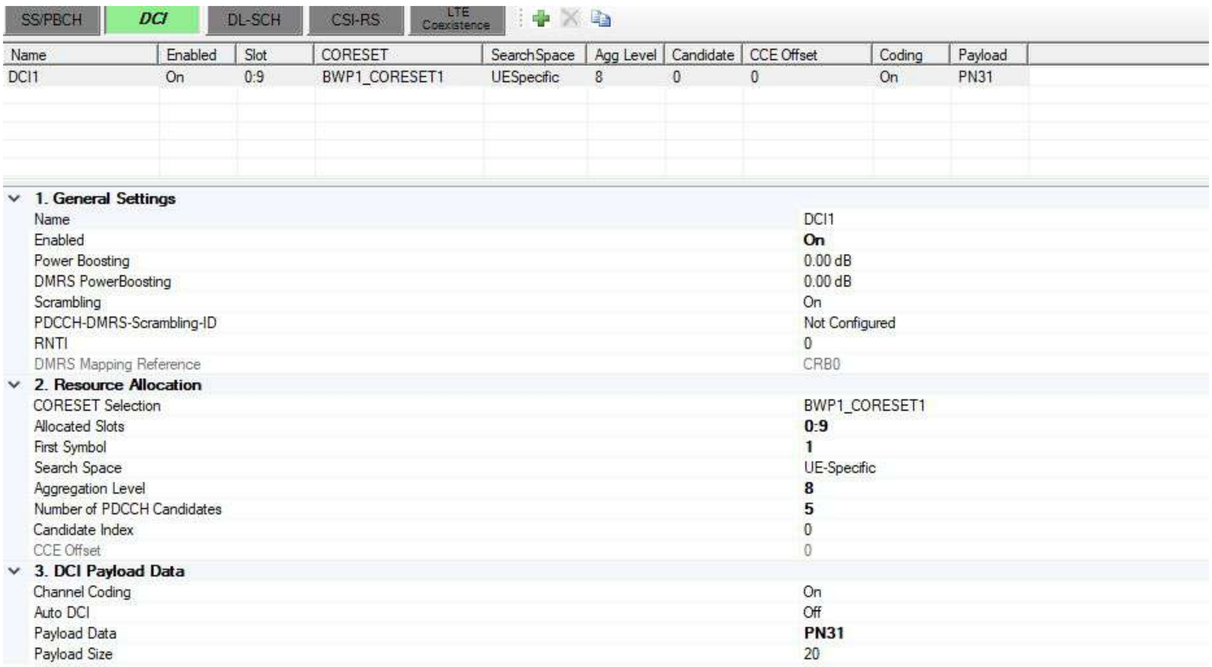

Figure 36.b :PDCCH input parameters

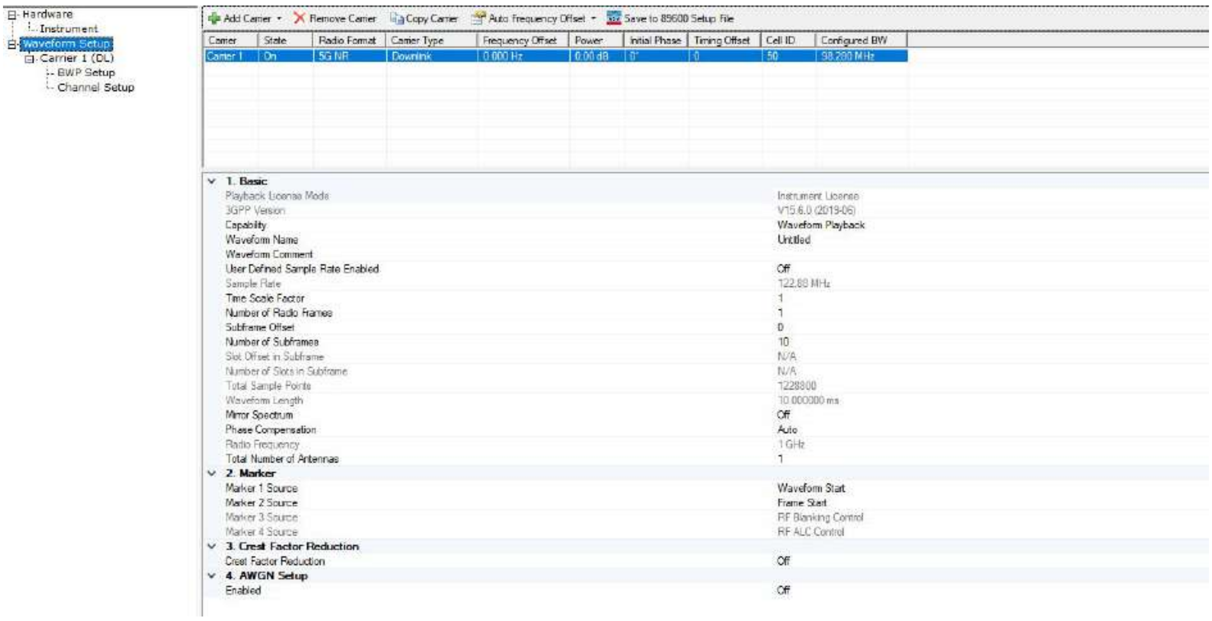

Figure 36.d :PDCCH input parameters

The above figures show the various input parameters for the DCI (PDCCH) channel.

The following figures show the outputs of the DCI channel in accordance with the above given input parameters.

One of the output is showing the Channel allocation and the other one is showing the Spectrum of the output.

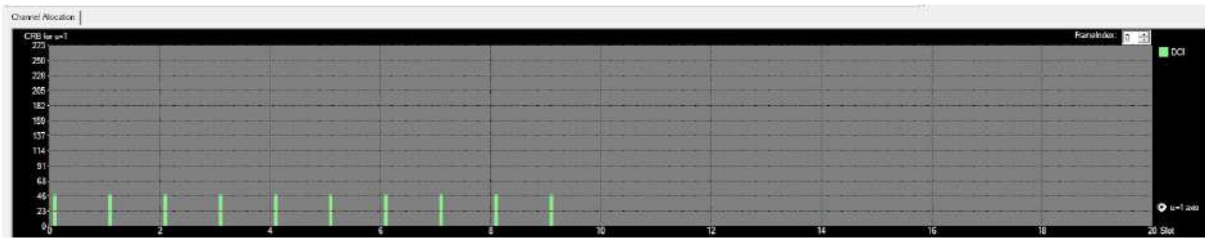

Figure 37 :PDCCH Channel Allocation

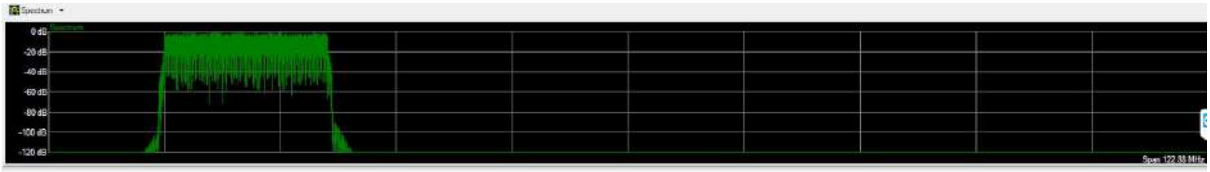

Figure 37. a :PDCCH Spectrum

3. CSIRS

The following figures will show the Signal Studio pro inputs and outputs generated for CSIRS.

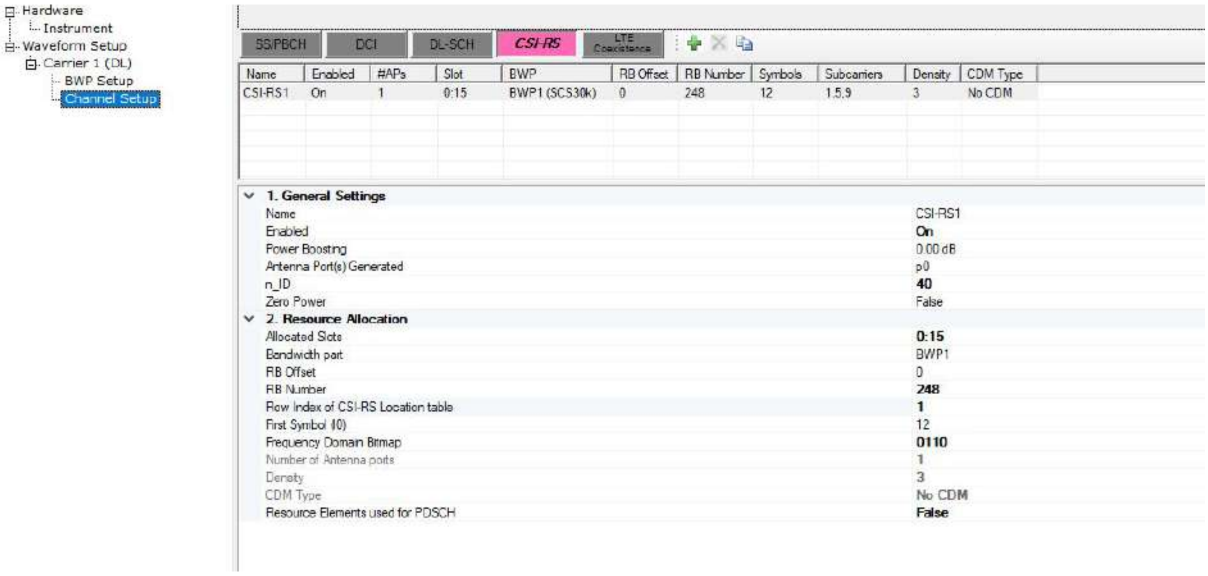

Figure 38 :CSIRS input parameters

This figure shows the input parameters for the CSIRS.

The following figure shows the outputs according to the given inputs.

The simulation was done for 50 Resource Blocks only.

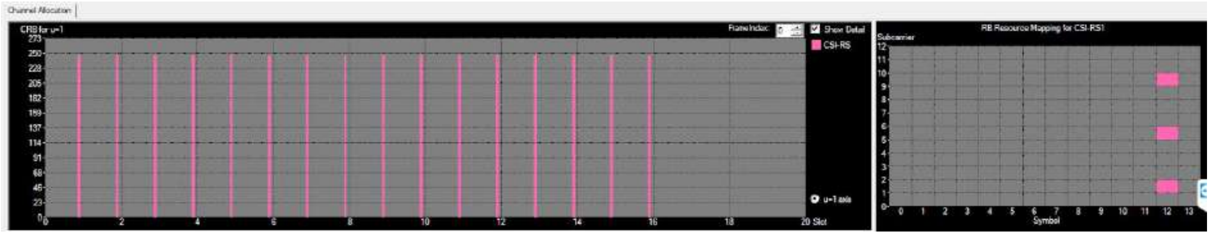

Figure 39 :CSIRS Channel Allocation

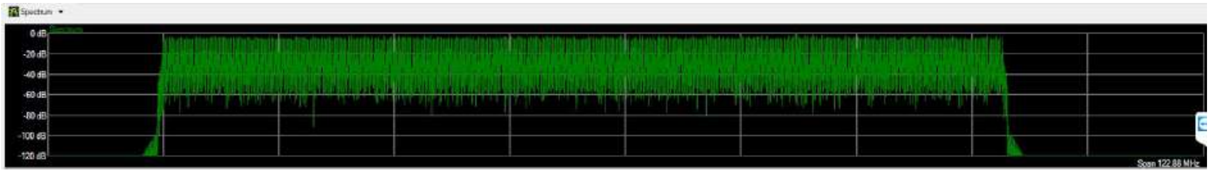

Figure 39.a :CSIRS Spectrum

4. PBCH

PBCH stands for Physical Broadcast Channel.

The following figures show the inputs and outputs for the PBCH/SSB Channel.

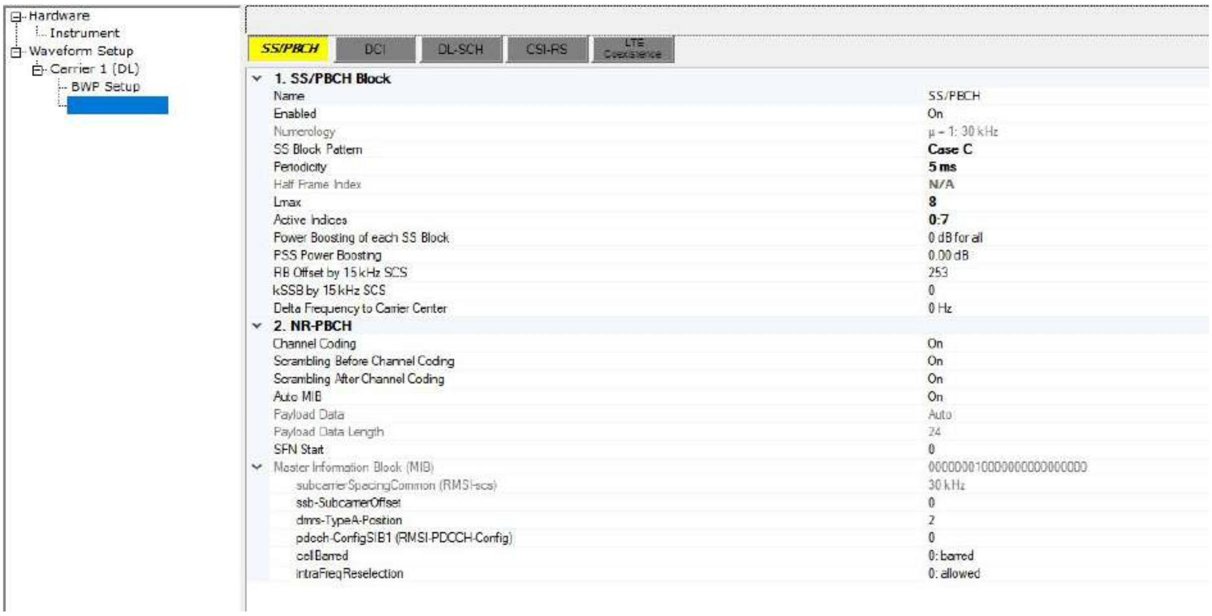

Figure 40 :PBCH input parameters

The above input parameters were fed to Signal Studio Pro and the following outputs were generated.

The output files show the Channel allocation (Resource Grid) and Spectrum for the PBCH .

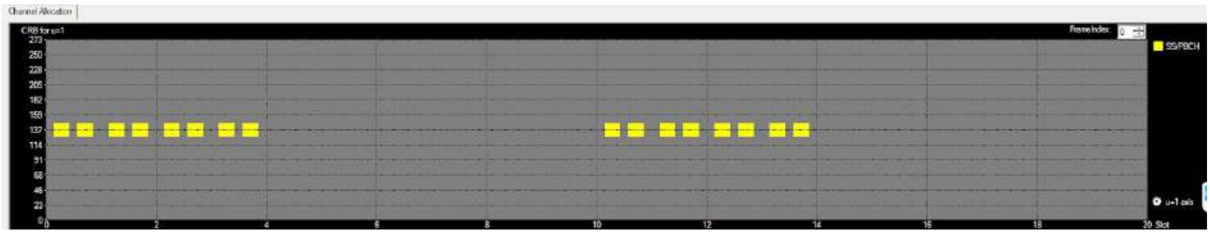

Figure 41 :PBCH Channel Allocation

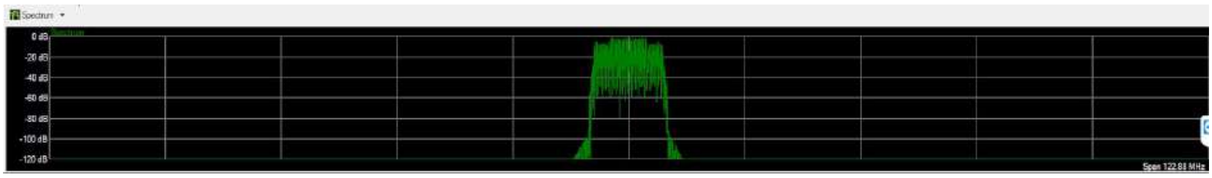

Figure 41.a : PBCH Spectrum

The above simulations were done for the Physical downlink Channels.

The following simulations will be for the Uplink Physical Channels.

5. SRS

The following figures will show the simulation input and outputs for the Uplink SRS.

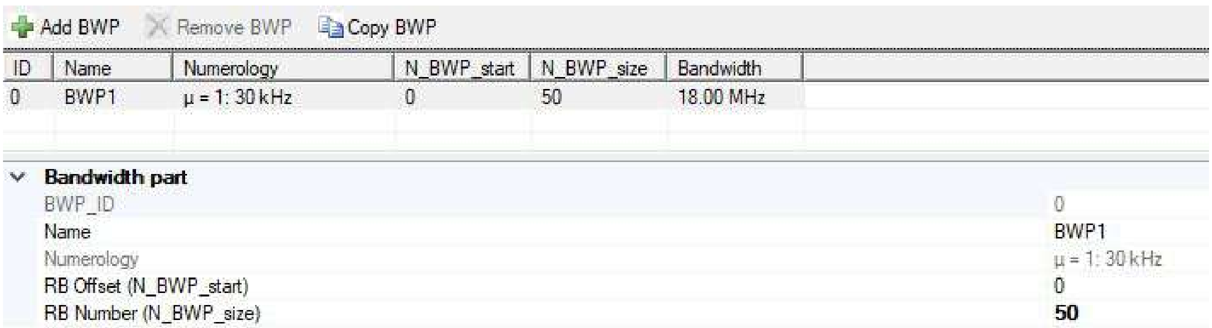

Figure 42 :SRS input parameters

These are the input parameters set for the BWP (BandWidth Part)

The Resource Blocks are set to 50.

The following figure will show the parameters for the Channel Setup.

Figure 42.a :SRS input parameters

The outputs Resource Grid for SRS is given below:

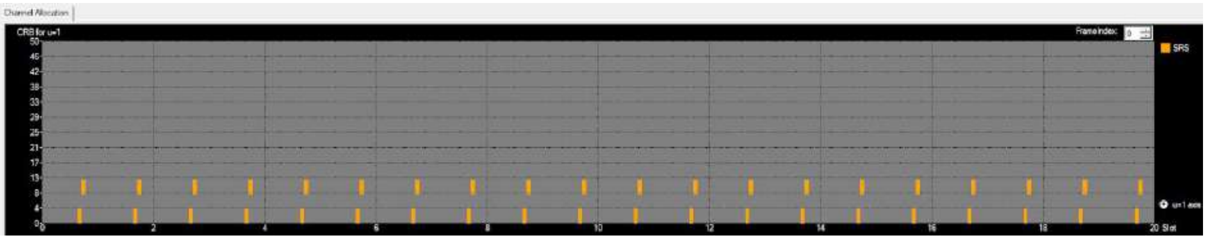

Figure 43 : SRS Channel Allocation

6. PUSCH

The following figures show the input parameters for PUSCH generation in Signal Studio and their respective output.

Figure 44 :PUSCH input parameters

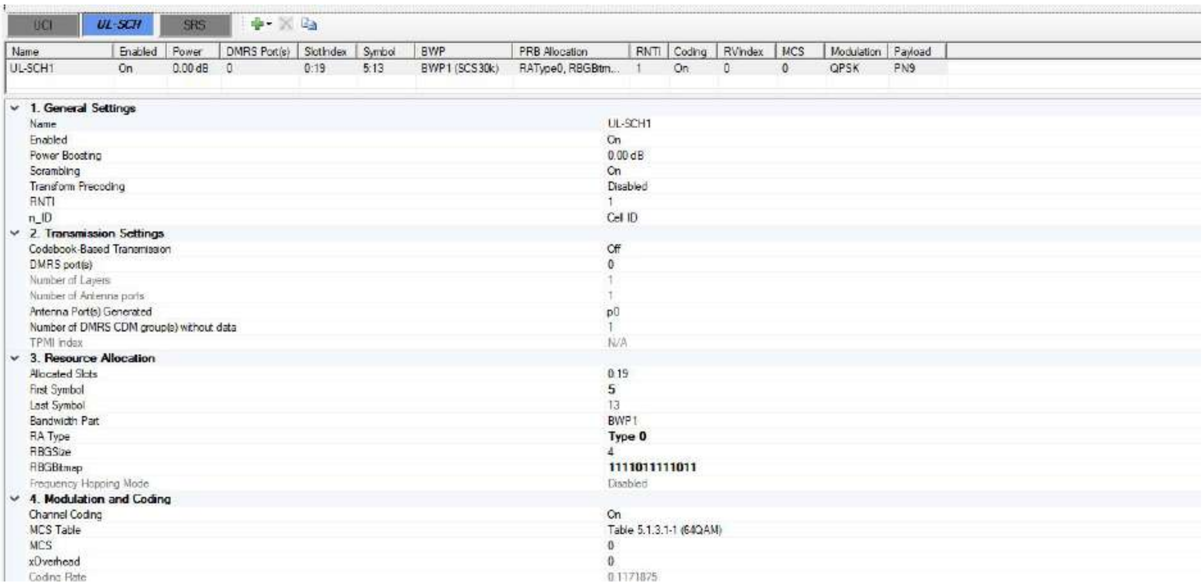

Figure 44.a :PUSCH input parameters

4. Modulation and Coding	
Channel Coding	On
MCS Table	Table 5.1.3.1-1 (64QAM)
MCS	0
xOverhead	0
Coding Rate	0.1171875
Modulation	QPSK
Transport Block Size	**984**
Base Graph	2
LBRM	False
Payload Data	PN9
5. HARQ Settings	
RV Index	0
CBG Transmission	Off
CRC Error Flag	0
6. DMRS Settings	
n_SCID	**1**
N_ID_nSCID	**20**
DMRS PowerBoosting	0.00 dB
DMRS Configuration	Type 1
DMRS Duration	**Double Symbol**
DMRS-add-pos	0
PUSCH Mapping	**Type B**
DMRS-typeA-pos	2

Figure 44.b :PUSCH input parameters

7. PTRS Settings	
PTRS Enabled	Off
PTRS PowerBoosting	0.00 dB
PTRS port(s)	0
Frequency Density (K_PTRS)	2
Time Density (L_PTRS)	1
PTRS RE Offset	00
8. UCI on PUSCH	
UL-SCH Enabled	On
uci-on-pusch-scaling	0.5
HARQACK	
Enabled	Off
Beta Offset Index	0
CSI1	
Enabled	Off
CSI2	
Enabled	Off

Figure 44.c :PUSCH input parameters

These were the input parameters for the Uplink PUSCH channel.

The simulation is done for Resource Allocation Type 0.

The output resource grid is given below:

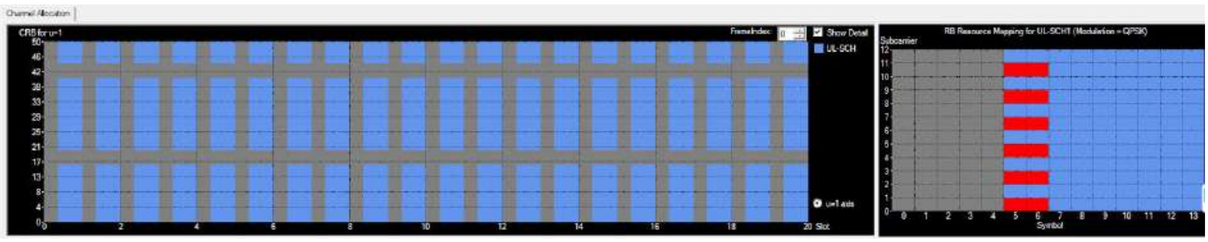

Figure 45 :PUSCH Channel Allocation

7. PRACH

The following simulation is done for the Physical Random Access Channel.

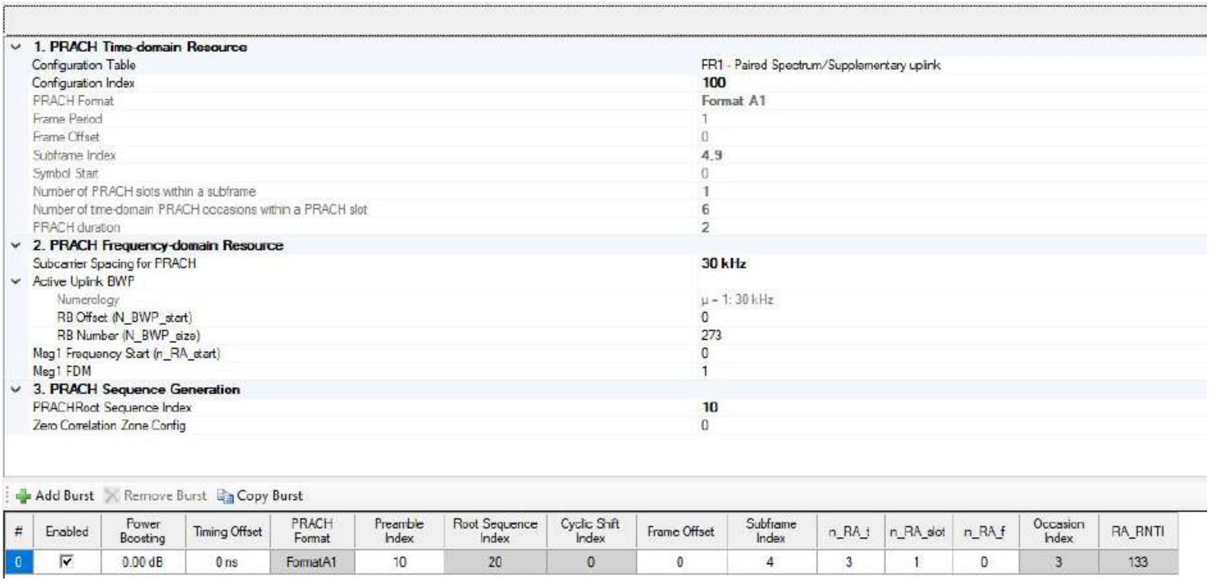

Figure 46 :PRACH input parameters

The following figures show the Channel Allocation and Spectrum for PRACH.\

This shows the Output for Suframe 4, similar output is also for Subframe 9.

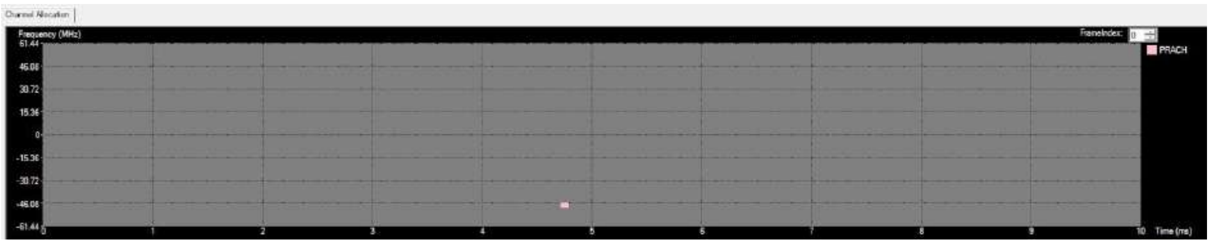

Figure 47 :PRACH Channel Allocation

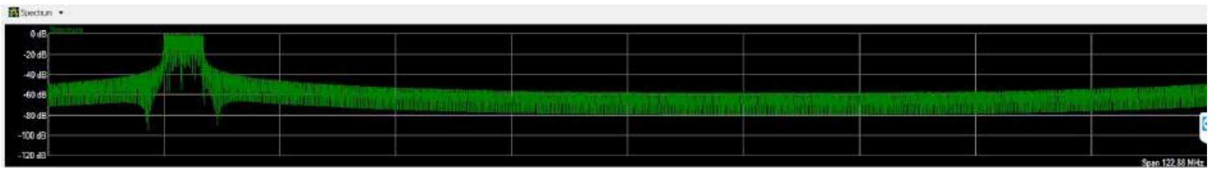

Figure 47.a :PRACH Spectrum

8. PUCCH

The following figures show the input parameters for PUCCH Format 4.

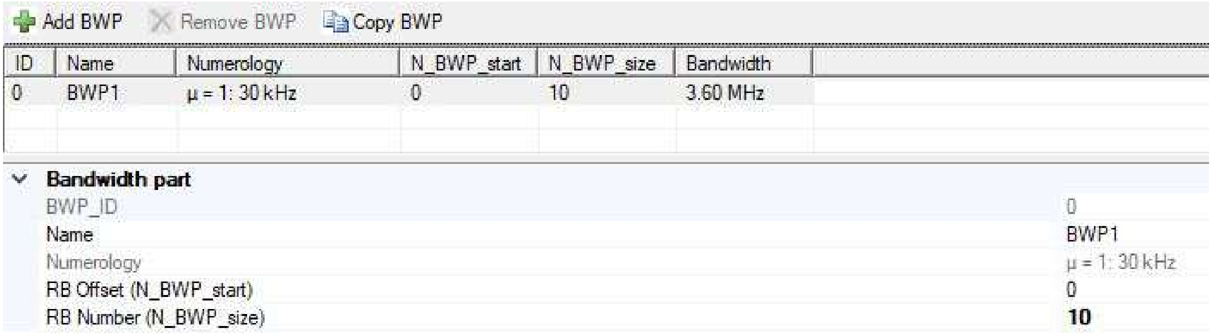

Figure 48 :PUCCH input parameters

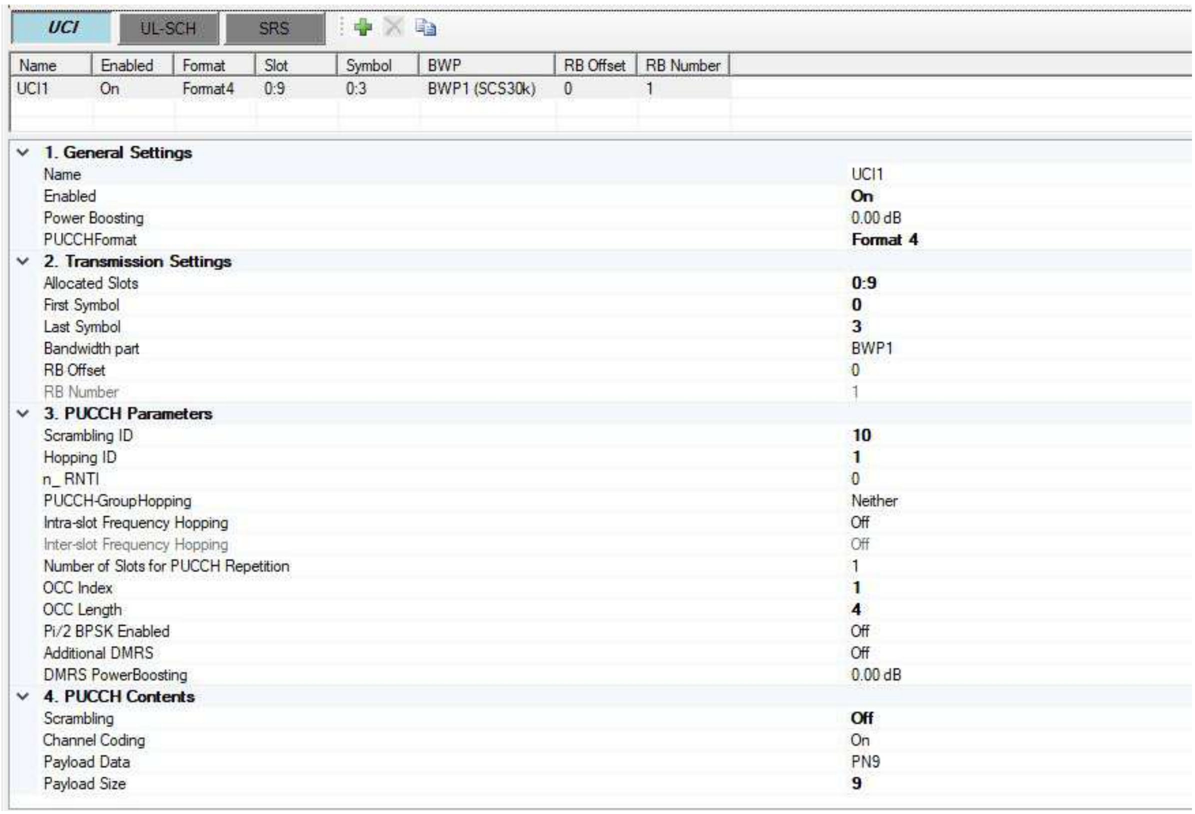

Figure 48.a :PUCCH input parameters

The following figure shows the output with respect to the given inputs.

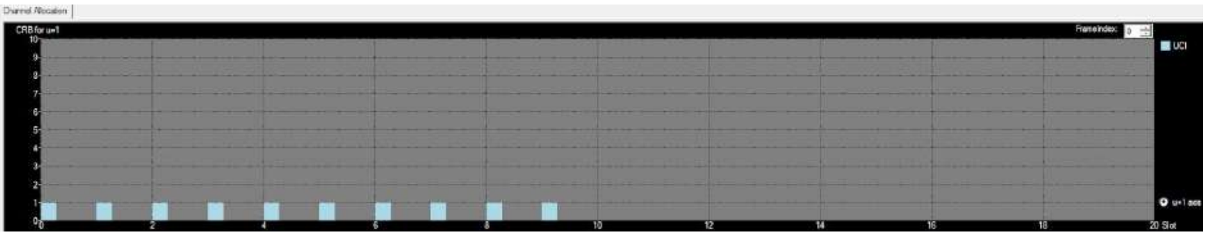

Figure 49 :PUCCH Channel Allocation

CHAPTER 7

CONCLUSION

All the Physical Channels and Signals mentioned above are simulated using SystemVue and Signal Studio Pro. Various test vectors are generated for different sets of inputs. All these input output test vectors are saved to the lab PC at 5G Testbed. These test vectors form the basis for verification for each stage of the software simulation and hardware implementation at 5G Testbed.

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