5G Toolbox™

User's Guide

MATLAB®

R2019b

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5G Toolbox™ User Guide

Revision History

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End-To-End Simulation

Transmission over MIMO Channel Model with Delay Profile TDL

Display waveform spectrum received through a Tapped Delay Line (TDL) multi-input/multi-output (MIMO) channel model from TR 38.901 Section 7.7.2 using an `nrTDLChannel` System object.

Define the channel configuration structure using an `nrTDLChannel` System object. Use delay profile TDL-C from TR 38.901 Section 7.7.2, a delay spread of 300 ns, and UT velocity of 30 km/h:

```
v = 30.0;                    % UT velocity in km/h
fc = 4e9;                    % carrier frequency in Hz
c = physconst('lightspeed'); % speed of light in m/s
fd = (v*1000/3600)/c*fc;     % UT max Doppler frequency in Hz

tdl = nrTDLChannel;
tdl.DelayProfile = 'TDL-C';
tdl.DelaySpread = 300e-9;
tdl.MaximumDopplerShift = fd;
```

Create a random waveform of 1 subframe duration with 1 antenna.

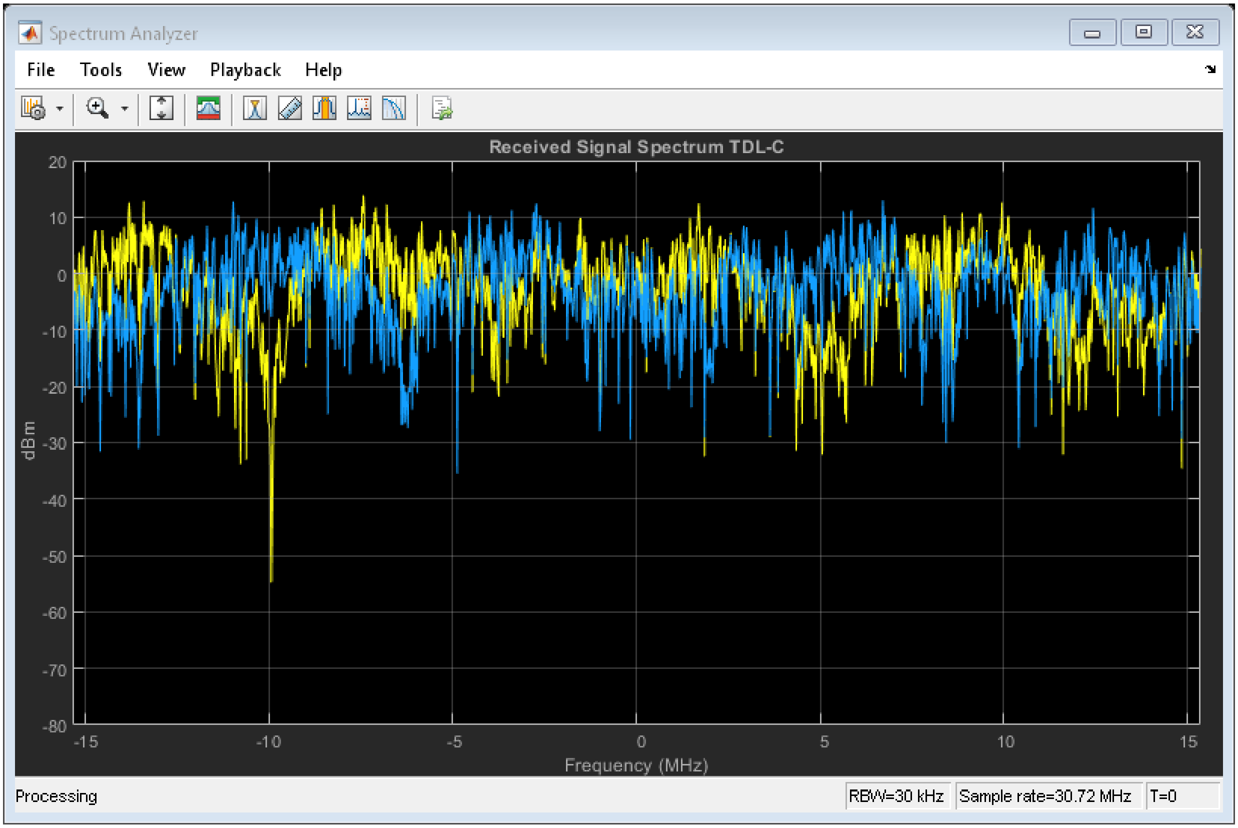
```
SR = 30.72e6;
T = SR * 1e-3;
tdl.SampleRate = SR;
tdlinfo = info(tdl);
Nt = tdlinfo.NumTransmitAntennas;

txWaveform = complex(randn(T,Nt),randn(T,Nt));
```

Transmit the input waveform through the channel.

```
rxWaveform = tdl(txWaveform);
```

Plot the received waveform spectrum.

```
analyzer = dsp.SpectrumAnalyzer('SampleRate',tdl.SampleRate);
analyzer.Title = ['Received Signal Spectrum ' tdl.DelayProfile];
analyzer(rxWaveform);
```



See Also

System Objects
`nrTDLChannel`

Plot Path Gains for TDL-E Delay Profile with SISO

Plot the path gains of a Tapped Delay Line (TDL) single-input/single-output (SISO) channel using an `nrTDLChannel` System object.

Configure a channel with delay profile TDL-E from TR 38.901 Section 7.7.2. Set the maximum Doppler shift to 70 Hz and enable path gain output

```
tdl = nrTDLChannel;
tdl.SampleRate = 500e3;
tdl.MaximumDopplerShift = 70;
tdl.DelayProfile = 'TDL-E';
```

Configure transmit and receive antenna arrays for SISO operation.

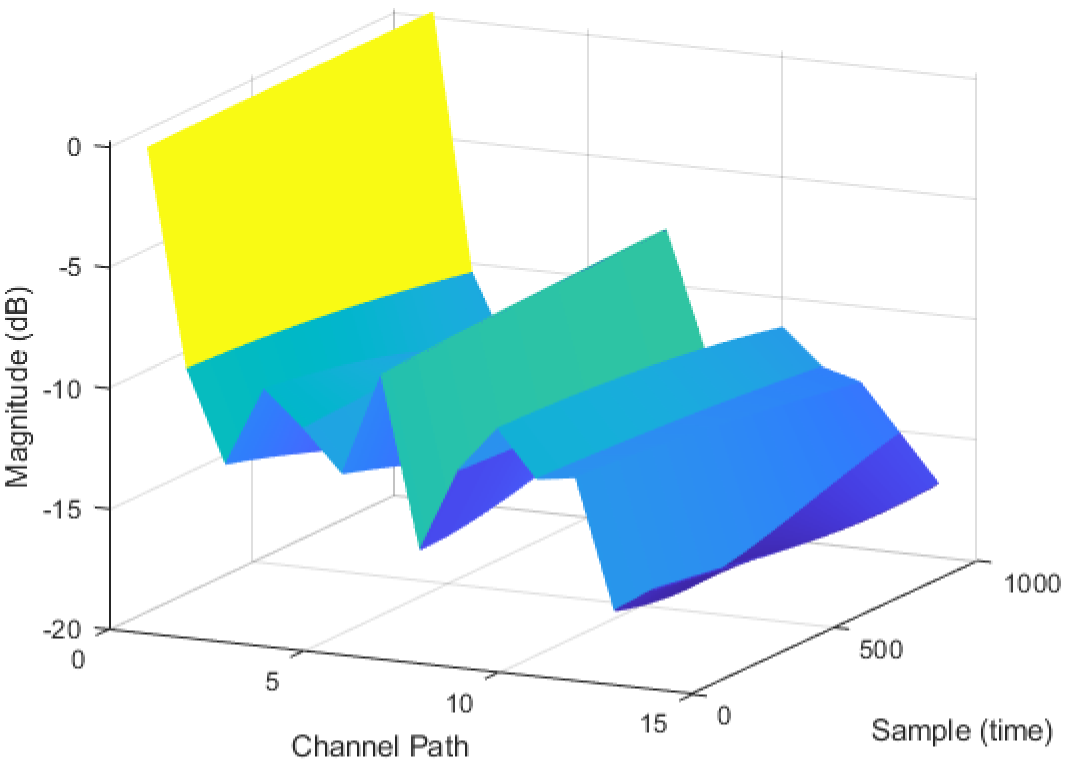
```
tdl.NumTransmitAntennas = 1;
tdl.NumReceiveAntennas = 1;
```

Create a dummy input signal. The length of the input determines the time samples of the generated path gain.

```
in = zeros(1000,tdl.NumTransmitAntennas);
```

To generate the path gains, call the channel on the input. Plot the results.

```
[~, pathGains] = tdl(in);
mesh(10*log10(abs(pathGains)));
view(26,17); xlabel('Channel Path');
ylabel('Sample (time)'); zlabel('Magnitude (dB)');
```



See Also

System Objects
`nrTDLChannel`

Reconstruct Channel Impulse Response Using CDL Channel Path Filters

Reconstruct the channel impulse response and perform timing offset estimation using path filters of a Clustered Delay Line (CDL) channel model with delay profile CDL-D from TR 38.901 Section 7.7.1.

Define the channel configuration structure using an `nrCDLChannel` System object. Use delay profile CDL-D, a delay spread of 10 ns, and UT velocity of 15 km/h:

```
v = 15.0;                    % UT velocity in km/h
fc = 4e9;                    % carrier frequency in Hz
c = physconst('lightspeed'); % speed of light in m/s
fd = (v*1000/3600)/c*fc;     % UT max Doppler frequency in Hz

cdl = nrCDLChannel;
cdl.DelayProfile = 'CDL-D';
cdl.DelaySpread = 10e-9;
cdl.CarrierFrequency = fc;
cdl.MaximumDopplerShift = fd;
```

Configure the transmit array as [M N P Mg Ng] = [2 2 2 1 1], representing 1 panel (Mg=1, Ng=1) with a 2-by-2 antenna array (M=2, N=2) and P=2 polarization angles. Configure the receive antenna array as [M N P Mg Ng] = [1 1 2 1 1], representing a single pair of cross-polarized co-located antennas.

```
cdl.TransmitAntennaArray.Size = [2 2 2 1 1];
cdl.ReceiveAntennaArray.Size = [1 1 2 1 1];
```

Create a random waveform of 1 subframe duration with 8 antennas.

```
SR = 15.36e6;
T = SR * 1e-3;
cdl.SampleRate = SR;
cdlinfo = info(cdl);
Nt = cdlinfo.NumTransmitAntennas;

txWaveform = complex(randn(T,Nt),randn(T,Nt));
```

Transmit the input waveform through the channel.

```
[rxWaveform,pathGains] = cdl(txWaveform);
```

Obtain the path filters used in channel filtering.

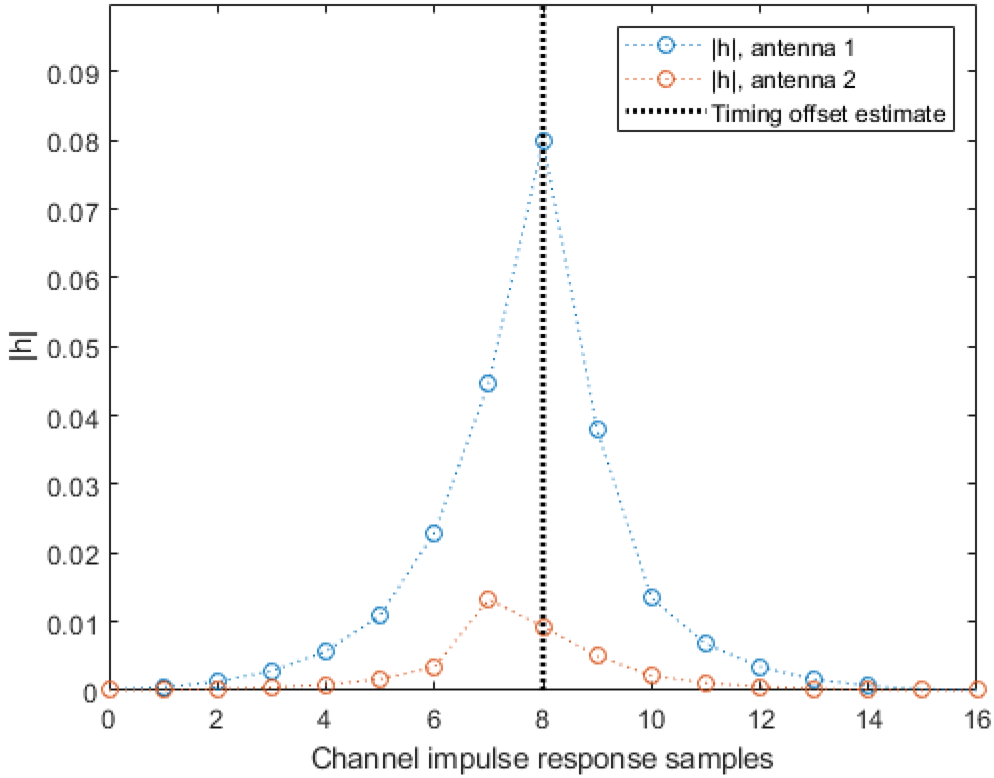
```
pathFilters = getPathFilters(cdl);
```

Perform timing offset estimation using `nrPerfectTimingEstmate`.

```
[offset,mag] = nrPerfectTimingEstimate(pathGains,pathFilters);
```

Plot the magnitude of the channel impulse response.

```
[Nh,Nr] = size(mag);
plot(0:(Nh-1),mag,'o:');
hold on;
plot([offset offset],[0 max(mag(:))*1.25],'k:','LineWidth',2);
axis([0 Nh-1 0 max(mag(:))*1.25]);
legends = "|h|, antenna " + num2cell(1:Nr);
legend([legends "Timing offset estimate"]);
ylabel('|h|');
xlabel('Channel impulse response samples');
```



See Also

Functions
`nrPerfectTimingEstimate`

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Signal Reception

Extract PBCH Symbols and Channel Estimates for Decoding

Extract physical broadcast channel (PBCH) symbols from a received grid and associated channel estimates in preparation for decoding a beamformed PBCH.

PBCH Coding and Beamforming

Create a random sequence of binary values corresponding to a BCH codeword. The length of the codeword is 864, as specified in TS 38.212 Section 7.1.5. Using the codeword, create symbols and indices for a PBCH transmission. Specify the physical layer cell identity number.

```
E = 864;
cw = randi([0 1],E,1);
ncellid = 17;
v = 0;
pbchTxSym = nrPBCH(cw,ncellid,v);
pbchInd = nrPBCHIndices(ncellid);
```

Use `nrExtractResources` to create indices for the two transmit antennas of a beamformed PBCH. Use these indices to map the beamformed PBCH into the transmitter resource array.

```
P = 2;
txGrid = zeros([240 4 P]);
F = [1 1i];
[~,bfInd] = nrExtractResources(pbchInd,txGrid);
txGrid(bfInd) = pbchTxSym*F;
```

OFDM modulate the PBCH symbols mapped into the transmitter resource array.

```
txWaveform = ofdmmod(txGrid,256,[22 18 18 18],[1:8 249:256].');
```

PBCH Transmission and Decoding

Create and apply a channel matrix to the waveform. Receive the transmitted waveforms.

```
R = 3;
H = dftmtx(max([P R]));
H = H(1:P,1:R);
H = H/norm(H);
rxWaveform = txWaveform*H;
```

Create channel estimates including beamforming.

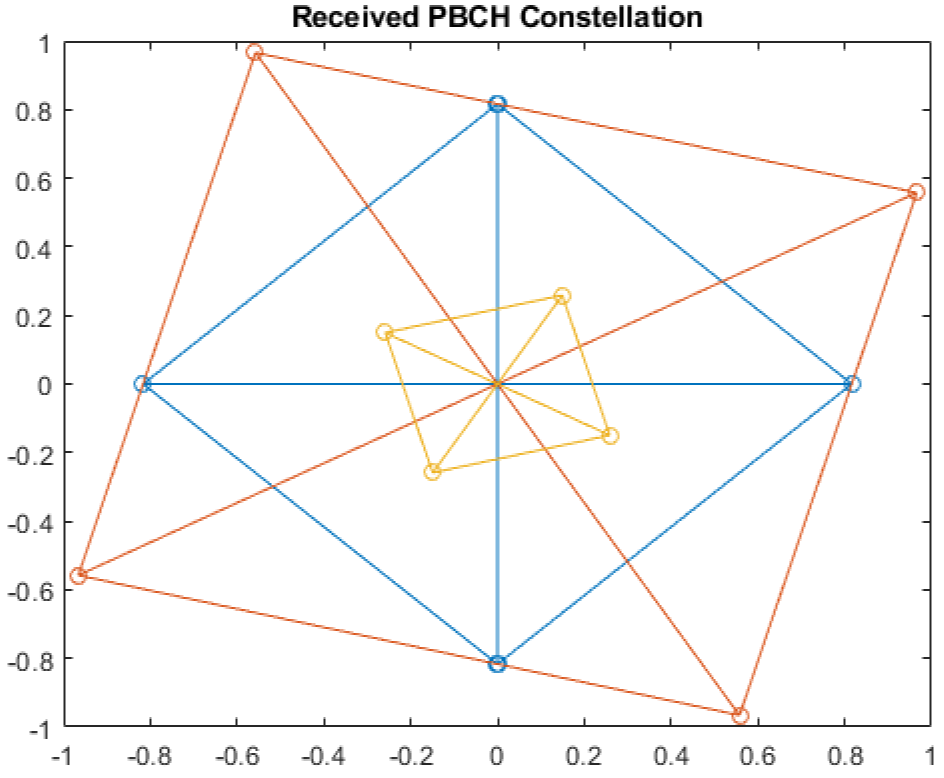
```
hEstGrid = repmat(permute(H.'*F.',[3 4 1 2]),[240 4]);
nEst = 0;
```

Demodulate the received waveform using orthogonal frequency division multiplexing (OFDM).

```
rxGrid = ofdmdemod(rxWaveform,256,[22 18 18 18],0,[1:8 249:256].');
```

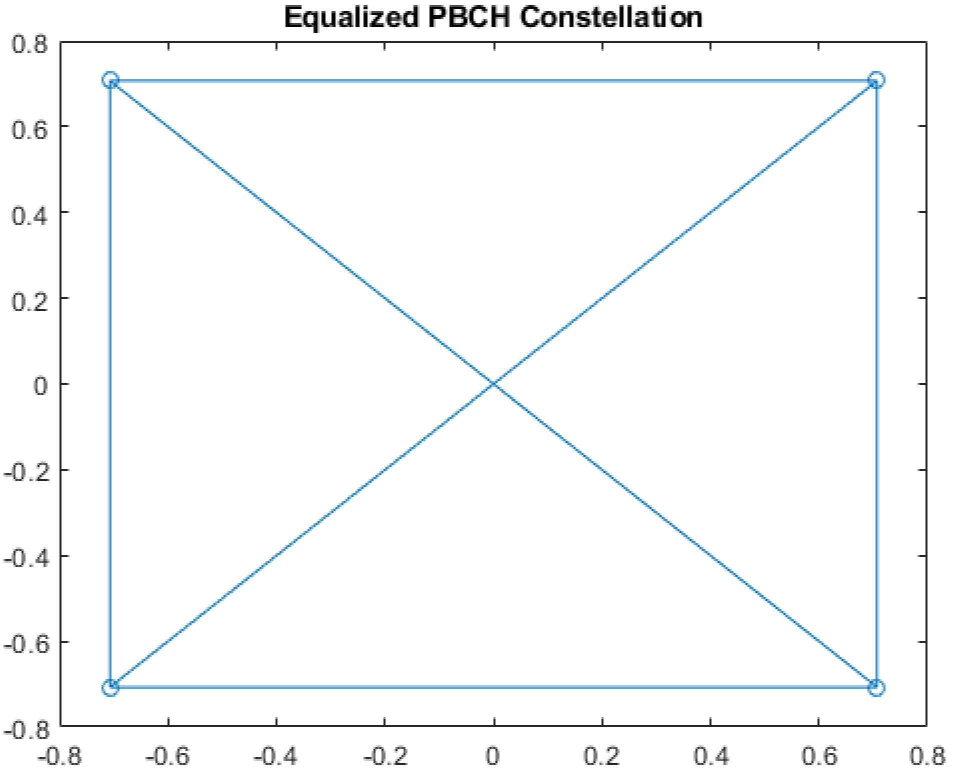
In preparation for PBCH decoding, extract symbols from the received grid and the channel estimate grid.

```
[pbchRxSym,pbchHestSym] = nrExtractResources(pbchInd,rxGrid,hEstGrid);
figure;
plot(pbchRxSym,'o:');
title('Received PBCH Constellation');
```



Equalize the symbols by performing MMSE equalization on the extracted resources. Plot the results.

```
pbchEqSym = nrEqualizeMMSE(pbchRxSym,pbchHestSym,nEst);
figure;
plot(pbchEqSym,'o:');
title('Equalized PBCH Constellation');
```



Retrieve soft bits by performing PBCH decoding on the equalized symbols.

```
pbchBits = nrPBCHDecode(pbchEqSym,ncellid,v)
```

```
pbchBits = 864×1
10^10 ×

   -2.0000
   -2.0000
    2.0000
   -2.0000
   -2.0000
    2.0000
    2.0000
```

```
  -2.0000
  -2.0000
  -2.0000
     ⋮
```

See Also

Functions
nrEqualizeMMSE | nrExtractResources

3

Code Generation and Deployment

What is C Code Generation from MATLAB?

You can use 5G Toolbox together with MATLAB® Coder™ to:

- Create a MEX file to speed up your MATLAB application.
- Generate ANSI®/ISO® compliant C/C++ source code that implements your MATLAB functions and models.
- Generate a standalone executable that runs independently of MATLAB on your computer or another platform.

In general, the code you generate using the toolbox is portable ANSI C code. In order to use code generation, you need a MATLAB Coder license. For more information, see "Getting Started with MATLAB Coder" (MATLAB Coder).

Using MATLAB Coder

Creating a MATLAB Coder MEX file can substantially accelerate your MATLAB code. It is also a convenient first step in a workflow that ultimately leads to completely standalone code. When you create a MEX file, it runs in the MATLAB environment. Its inputs and outputs are available for inspection just like any other MATLAB variable. You can then use MATLAB tools for visualization, verification, and analysis.

The simplest way to generate MEX files from your MATLAB code is by using the `codegen` function at the command line. For example, if you have an existing function, `myfunction.m`, you can type the commands at the command line to compile and run the MEX function. `codegen` adds a platform-specific extension to this name. In this case, the `"mex"` suffix is added.

```
codegen myfunction.m
myfunction_mex;
```

Within your code, you can run specific commands either as generated C code or by using the MATLAB engine. In cases where an isolated command does not yet have code generation support, you can use the `coder.extrinsic` command to embed the command in your code. This means that the generated code reenters the MATLAB environment when it needs to run that particular command. This is also useful if you want to embed commands that cannot generate code (such as plotting functions).

To generate standalone executables that run independently of the MATLAB environment, create a MATLAB Coder project inside the MATLAB Coder Integrated Development

Environment (IDE). Alternatively, you can call the `codegen` command in the command line environment with appropriate configuration parameters. A standalone executable requires you to write your own `main.c` or `main.cpp` function. See “Generating Standalone C/C++ Executables from MATLAB Code” (MATLAB Coder) for more information.

C/C++ Compiler Setup

Before using `codegen` to compile your code, you must set up your C/C++ compiler. For 32-bit Windows platforms, MathWorks® supplies a default compiler with MATLAB. If your installation does not include a default compiler, you can supply your own compiler. For the current list of supported compilers, see Supported and Compatible Compilers on the MathWorks website. Install a compiler that is suitable for your platform, then read “Setting Up the C or C++ Compiler” (MATLAB Coder). After installation, at the MATLAB command prompt, run `mex -setup`. You can then use the `codegen` function to compile your code.

Functions and System Objects That Support Code Generation

All 5G Toolbox functions and System objects support code generation.

See Also

Functions
`codegen` | `mex`

More About

- “Code Generation Workflow” (MATLAB Coder)
- Generate C Code from MATLAB Code Video

Functions and System Objects Supported for MATLAB Coder

You can generate efficient C/C++ code for all 5G Toolbox functions and System objects by using the MATLAB Coder product (requires a license).

An asterisk (*) indicates that the reference page has usage notes and limitations for C/C++ code generation.

getPathFilters	Get path filter impulse response for link-level MIMO fading channel
getTransportBlock	Get transport block from UL-SCH or DL-SCH encoder
info	Get characteristic information about link-level MIMO fading channel
nrBCH	Broadcast channel (BCH) encoding
nrBCHDecode*	Broadcast channel (BCH) decoding
nrCarrierConfig	Carrier configuration parameters
nrCDLChannel*	Send signal through CDL channel model
nrChannelEstimate	Practical channel estimation
nrCodeBlockDesegmentLDPC	LDPC code block desegmentation and CRC decoding
nrCodeBlockSegmentLDPC	LDPC code block segmentation and CRC attachment
nrCRCDecode	Decode and remove cyclic redundancy check (CRC)
nrCRCEncode	Calculate and append cyclic redundancy check (CRC)
nrCSIRS	Generate CSI-RS symbols
nrCSIRSConfig	CSI-RS configuration parameters
nrCSIRSIndices	Generate CSI-RS resource element indices
nrDCIDecode*	Decode downlink control information (DCI)
nrDCIEncode	Encode downlink control information (DCI)
nrDLSCH*	Apply DL-SCH encoder processing chain
nrDLSCHDecoder*	Apply DL-SCH decoder processing chain
nrDLSCHInfo	Get downlink shared channel (DL-SCH) information

nrEqualizeMMSE	Minimum mean-squared error (MMSE) equalization
nrExtractResources*	Extract resource elements from resource array
nrLayerDemap	Layer demapping onto scrambled and modulated codewords
nrLayerMap	Layer mapping of modulated and scrambled codewords
nrLDPCDecode*	Low-density parity-check (LDPC) decoding
nrLDPCEncode	Low-density parity-check (LDPC) encoding
nrLowPAPRS*	Generate low peak-to-average power ratio (low-PAPR) sequence
nrPBCH*	Generate PBCH modulation symbols
nrPBCHDecode	Decode PBCH modulation symbols
nrPBCHDMRS*	Generate PBCH DM-RS symbols
nrPBCHDMRSIndices*	Generate PBCH DM-RS resource element indices
nrPBCHIndices*	Generate PBCH resource element indices
nrPBCHPRBS*	Generate PBCH scrambling sequence
nrPDCCH*	Generate PDCCH modulation symbols
nrPDCCHDecode	Decode PDCCH modulation symbols
nrPDCCHPRBS*	Generate PDCCH scrambling sequence
nrPDSCH*	Generate PDSCH modulation symbols
nrPDSCHDecode	Decode PDSCH modulation symbols
nrPDSCHPRBS*	Generate PDSCH scrambling sequence
nrPerfectChannelEstimate	Perfect channel estimation
nrPerfectTimingEstimate	Perfect timing estimation
nrPolarDecode*	Polar decoding
nrPolarEncode	Polar encoding
nrPRBS*	Generate PRBS
nrPSS*	Generate PSS symbols
nrPSSIndices*	Generate PSS resource element indices

nrPUCCH0*	Generate PUCCH format 0 modulation symbols
nrPUCCH1*	Generate PUCCH format 1 modulation symbols
nrPUCCH2*	Generate PUCCH format 2 modulation symbols
nrPUCCH3*	Generate PUCCH format 3 modulation symbols
nrPUCCH4*	Generate PUCCH format 4 modulation symbols
nrPUCCHHoppingInfo	Get PUCCH hopping information
nrPUCCHPRBS*	Generate PUCCH scrambling sequence
nrPUSCH*	Generate PUSCH modulation symbols
nrPUSCHCodebook	Generate PUSCH precoding matrix
nrPUSCHDecode	Decode PUSCH modulation symbols
nrPUSCHDescramble	Perform PUSCH descrambling
nrPUSCHPRBS*	Generate PUSCH scrambling sequence
nrPUSCHScramble	Perform PUSCH scrambling
nrRateMatchLDPC	Low-density parity-check (LDPC) rate matching
nrRateMatchPolar	Polar rate matching
nrRateRecoverLDPC	Low-density parity-check (LDPC) rate recovery
nrRateRecoverPolar	Polar rate recovering
nrSSS*	Generate SSS symbols
nrSSSIndices*	Generate SSS resource element indices
nrSymbolDemodulate*	Demodulate and convert symbols to bits
nrSymbolModulate*	Generate modulated symbols
nrTDLChannel*	Send signal through TDL channel model
nrTimingEstimate	Practical timing estimation
nrTransformDeprecode	Recover transform deprecoded symbols
nrTransformPrecode	Generate transform precoded symbols

nrUCIDecode*	Decode uplink control information (UCI)
nrUCIEncode	Encode uplink control information (UCI)
nrULSCH*	Apply UL-SCH encoder processing chain
nrULSCHDecoder*	Apply UL-SCH decoder processing chain
nrULSCHInfo	Get uplink shared channel (UL-SCH) information
resetSoftBuffer	Reset soft buffer for HARQ process in UL-SCH or DL-SCH decoder
setTransportBlock	Load transport block into UL-SCH or DL-SCH encoder

See Also

More About

- “What is C Code Generation from MATLAB?” on page 3-2