What’s New in MATLAB and Simulink for Signal Processing

Jonas Rutström
Senior Application Engineer
So, what’s new?
NORDIC MATLAB EXPO 2014
R2014b → R2016a
“What’s New in MATLAB and Simulink for Signal Processing”
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
A few words about “What’s New?”

Details
A few words about “What’s New?”

Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
Signal Processing Engineers…
Signal Processing Engineers…

Develop algorithms

write MATLAB code.

Analyze data
Signal Processing Engineers... build Simulink models.

Model systems

Run simulations
Signal Processing Engineers...

combine MATLAB code and Simulink models together.
Signal Processing Engineers…

generate code.
Signal Processing Engineers…

connect software to hardware.
General trend... | *Idea to implementation*
Increased support for code generation and fixed point design

### Functions and Objects Supported for C and C++ Code Generation — Category List

You can generate efficient C and C++ code for a subset of MATLAB® built-in functions and toolbox functions, classes, and System objects that you call from MATLAB code. These functions, classes, and System objects are listed by MATLAB category or toolbox category in the following tables.

---

#### Signal Processing in MATLAB

<table>
<thead>
<tr>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>chdir</td>
</tr>
<tr>
<td>conv</td>
</tr>
<tr>
<td>fft</td>
</tr>
<tr>
<td>ifft2</td>
</tr>
<tr>
<td>ifftn</td>
</tr>
<tr>
<td>ifftshift</td>
</tr>
<tr>
<td>filter</td>
</tr>
<tr>
<td>freqspace</td>
</tr>
<tr>
<td>i fft</td>
</tr>
</tbody>
</table>

#### Signal Processing Toolbox

<table>
<thead>
<tr>
<th>Function</th>
</tr>
</thead>
</table>
| bartelsin
| bartlett  |
| beseval  |
| bitreverse|
| blackman |
| blackmanharris|
| bohmanwin|
| butter    |
| butterb   |
| butterd   |
| cfltrans  |
| chebwin   |
| chebap    |
| chebsd    |
| cheby    |
| cheby2   |
| db2psd    |
| dct       |

#### DSP System Toolbox

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>dsp.BurgAREstimator</td>
</tr>
<tr>
<td>dsp.BurgSpectrumEstimator</td>
</tr>
<tr>
<td>dsp.CepstralToLPC</td>
</tr>
<tr>
<td>dsp.CrossSpectrumEstimator</td>
</tr>
<tr>
<td>dsp.LevinsonSolver</td>
</tr>
<tr>
<td>dsp.LPCToCepstral</td>
</tr>
<tr>
<td>dsp.LPCToAutocorrelation</td>
</tr>
<tr>
<td>dsp.LPCToLSP</td>
</tr>
<tr>
<td>dsp.LPCToLSP</td>
</tr>
<tr>
<td>dsp.LPCToRC</td>
</tr>
<tr>
<td>dsp.LSFToLPC</td>
</tr>
<tr>
<td>dsp.LSPToLPC</td>
</tr>
<tr>
<td>dsp.RCToAutocorrelation</td>
</tr>
<tr>
<td>dsp.RCToLPC</td>
</tr>
<tr>
<td>dsp.SpectrumEstimator</td>
</tr>
<tr>
<td>dsp.TransferFunctionEstimator</td>
</tr>
</tbody>
</table>
Optimized libraries for DSPs

ARM Cortex-M and ARM Cortex-A Optimization

The DSP System Toolbox™ supports optimized C code generation for popular algorithms like FIR filtering and FFT on ARM® Cortex® M and ARM Cortex-A processors.
Some interesting additions...

**Changepoint Detection**
Find abrupt changes and statistical shifts in signals

- Determine "interesting" areas of an input signal
- Statistics supported:
  - Mean
  - Variance
  - Mean and variance
  - Linear Regression

```
load('enginePM.mat','x')
fndchangepnts(x,'Statistic','linear','MinThreshold',var(x))
```

**Dynamic Time Warping**
Stretch, align and compare signals with different time scales

- Obtain a measure of similarity of two signals trajectories
- Optional time alignment
- Popular distance metrics supported:
  - Euclidean
  - Squared Euclidean
  - Manhattan
  - Symmetric Kulback-Leibler

```
x = chirp(0:499,0,400,1/100);
y = cos(2*pi*5*(0:199)/200);
dw(x,y)
```

**Gap Filling**
Reconstruct missing samples using autoregressive modeling

- Allows finer prediction for many input signals.
- Automatic model selection via Akaike information criterion
- Multiple gaps.
- Optionally model non-stationary signals

```
load crash
x = na(x)
```

**Signal Analyzer App**
Visualize and compare multiple signals
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
Audio System Toolbox

Design and test audio processing systems
Audio System Toolbox

Design and test audio processing systems

- Libraries of audio processing algorithms and examples
- **Low-latency audio streaming** from and to standard audio interfaces (e.g. ASIO, CoreAudio, ALSA)
- **Live-tuning** of MATLAB and Simulink via UI and MIDI controls
- **VST** plugin generation to run on Digital Audio Workstations
Audio System Toolbox

Prototyping for product development

MATLAB algorithm → Early validation (listening tests) → Advanced prototyping or production
Audio System Toolbox

Use cases summary

- Desktop prototyping and listening tests
  - **Pain**: prototyping costly and time-consuming
  - **Solution**: real-time audio streaming in MATLAB and VST plugin generation

- Real-time custom measurements and signal analysis
  - **Pain**: test & measurement equipment not available or not customizable
  - **Solution**: real-time audio acquisition and *unlimited* custom analysis

- Audio algorithm design
  - **Pain**: re-inventing consolidated algorithms time-consuming
  - **Solution**: libraries of audio processing algorithms and examples
Audio System Toolbox

*Product ecosystem*

- **Requires**
  - MATLAB
  - Signal Processing Toolbox
  - DSP System Toolbox

- **Supports**
  - MATLAB
  - Simulink
  - C/C++ Code Generation
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
Antenna to Bits
System Design and Modelling

Communications Systems

- System Partitioning
- Link Budget Simulations
- System Integration

Radar / Sonar / Sensor Arrays

- Elaborating RF Architecture
- Component Simulation
- RF Subsystem Simulation
Antenna to Bits
System Design and Modelling

Antenna, Antenna arrays
type of element, # elements, coupling, edge effects

• Antenna Toolbox
• Phased Array System Toolbox

Channel
interference, clutter, noise

RF Impairments
frequency dependency, non-linearity, noise, mismatches

• SimRF
• RF Toolbox

Mixed-Signal
Continuous & discrete time

• Simulink (Simscape)
• DSP System Toolbox
• Control System Toolbox

Algorithms
beamforming, beamsteering, MIMO

• Phased Array System Toolbox
• Communications System Toolbox

Waveforms

• Phased Array System Toolbox
• Instrument Control Toolbox

System Design and Modelling

Antenna Toolbox
Phased Array System Toolbox

Communications System Toolbox
Phased Array System Toolbox

• Communications System Toolbox
• Phased Array System Toolbox
Antenna to Bits
System Design and Modelling

Antenna, Antenna arrays
- type of element, # elements, coupling, edge effects

Channel
- interference, clutter, noise

RF Impairments
- frequency dependency, non-linearity, noise, mismatches

Mixed-Signal
- Continuous & discrete time
- Simulink (Simscape)
- DSP System Toolbox
- Control System Toolbox

Algorithms
- beamforming, beamsteering, MIMO
- Phased Array System Toolbox
- Communications System Toolbox

Antenna Toolbox
- Phased Array System Toolbox

• Communication System Toolbox
- Phased Array System Toolbox

• SimRF
- RF Toolbox

• Phased Array System Toolbox
- Instrument Control Toolbox

Antenna to Bits System Design and Modelling

RX
LNA
TX
PA
ADC
DAC
DSP
Antenna to Bits
System Design and Modelling

Antenna, Antenna arrays
type of element, # elements, coupling, edge effects

- Antenna Toolbox
- Phased Array System Toolbox

![Image of Antenna to Bits diagram with TX, RX, LNA, ADC, DAC, and DSP components]
Antenna Toolbox

*Design, simulation and integration*

- **Easy design**
  - Library of parameterized antenna elements
  - Functionality for the design of linear and rectangular antenna arrays
  - No need for full CAD design

- **Rapid simulation setup**
  - Method of Moments field solver for port, field, and surface analysis
  - No need to be an EM expert

- **Seamless integration**
  - Model the antenna together with signal processing algorithms
  - Rapid iteration of different antenna scenarios for radar and communication systems design
Antenna Toolbox

Library of Available Geometries

- Dipole antennas
  - Dipole, Vee, Folded, Meander, Triangular bowtie, Rounded bowtie
- Monopole antennas
  - Monopole, Top hat, Inverted-F, inverted-L, Helix
- Patch antennas
  - Microstrip patch, PIFA
- Spirals
  - Equiangular, Archimedean
- Loops
  - Circular, rectangular
- Backing structures
  - Reflector and cavity
- Other common antennas
  - Yagi Uda, Slot, Vivaldi, Biquad, Horn
Antenna Toolbox

Custom Antenna Element Design

- Define your custom planar structure
  - Define the antenna geometry using PDE Toolbox
  - Define the mesh using MATLAB `delaunayTriangulation`
  - Use third party tools to generate a mesh structure
- Import 2D mesh with Antenna Toolbox
  - Define the feeding point
  - Analyse the antenna
Antenna Toolbox

**Dielectric Substrate Modelling**

- Antenna are often mounted on **substrates**
- Dielectric properties:

<table>
<thead>
<tr>
<th>Dielectric</th>
<th>Relative permittivity</th>
<th>Loss Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>&gt;1 (typically &lt;10)</td>
<td>&gt;0 (typically ~1e-3)</td>
</tr>
</tbody>
</table>

- Dielectric properties affect **resonance, bandwidth, efficiency, pattern**…
- Use the dielectric catalogue listing existing materials
- Define your **own** dielectric material

“metal” antenna (ideal conductor)

Free space (isolation)

Dielectric substrate
From antenna element to antenna array…
Phased Array System Toolbox
Array Antenna Design

```
>> a = linearArray
>> a.Element = p;
>> a.ElementSpacing = 0.1;
>> a.NumElements = 4;
>> layout(a);
>> patternElevation(a, 1.66e9, 0);
```
Phased Array System Toolbox

Custom Array Antenna Design

- Build regular arrays where you can change the **properties of individual elements** (rotation, size, tapering)
- Describe conformal (heterogeneous) arrays in terms of element type and arbitrary position

```matlab
>> arr = conformalArray;
>> d = dipole;
>> b = bowtieTriangular;
>> arr.Element = {d, b};
>> arr.ElementPosition(1,:) = [0 0 0];
>> arr.ElementPosition(2,:) = [0 0.5 0];
```
Phased Array System Toolbox

Model effects of quantized phase shift values on array patterns and responses

- Many phase shifters in real systems are quantized
- Allow customer to quickly see the effect of phase shifter quantization

```matlab
ant = phased.ULA('d');
sv = phased.SteeringVector('SensorArray', ant);
w1 = step(sv, 368, [20:10]);
release(sv);
w2 = step(sv, 368, [20:10]);
c = sv.PropagationSpeed;
pattern(ant, 368, -180:180, 0,'PropagationSpeed', c, 'Weights', w1 w2,...
    'CoordinateSystem', 'rectangular');
legend('Ideal Phase Shifter',...'
    'Quantized Phase Shifter', 'Location', 'best')
```
Antenna to Bits

*System Design and Modelling*

Antenna, Antenna arrays
type of element, # elements, coupling, edge effects

- Antenna Toolbox
- Phased Array System Toolbox

![Diagram of Antenna to Bits system design and modelling](image)
Antenna to Bits
System Design and Modelling

Antenna, Antenna arrays
type of element, # elements, coupling, edge effects

• Antenna Toolbox
• Phased Array System Toolbox

RF Impairments
frequency dependency, non-linearity, noise, mismatches

- TX
- RX
- LNA
- PA
- ADC
- DAC
- DSP

• SimRF
• RF Toolbox
RF Toolbox
RF Budget Analyzer

- Analytically compute gain, noise figure, and IP3 for cascaded RF components
- Specify components in terms of data sheet parameters and S-parameters
- Analyse the RF chain taking into account impedance mismatches
RF Toolbox

RF Budget Analyzer | Export to Sim RF

- Automatic testbench and SimRF model generation using the RF Budget Analyser App
- Validate simulation results using analytical computations
- Rapidly get started with Circuit Envelope simulation
Sim RF

Example | MIMO Front End with RF Beamforming

- Antenna coupling and loading (S-parameters)
- Antenna matching network
- RF and IF Filters described with Touchstone files
- IF demodulation with image rejection
- Non-linearity of the amplifiers
- Thermal Noise
- RF phase shifting and signal combiners
Sim RF

New and faster implementation of the AD9361 transmitter and receiver

http://www.mathworks.com/adi-rf
Antenna to Bits
System Design and Modelling

Antenna, Antenna arrays
type of element, # elements, coupling, edge effects

• Antenna Toolbox
• Phased Array System Toolbox

Channel
interference, clutter, noise

• Communications System Toolbox
• Phased Array System Toolbox

Antenna Toolbox
• Phased Array System Toolbox

RF Impairments
frequency dependency, non-linearity, noise, mismatches

• SimRF
• RF Toolbox

Mixed-Signal
Continuous & discrete time

• Simulink (Simscape)
• DSP System Toolbox
• Control System Toolbox

Algorithms
beamforming, beamsteering, MIMO

• Phased Array System Toolbox
• Communications System Toolbox

Waveforms

• Phased Array System Toolbox
• Instrument Control Toolbox

RX

TX

DAC

ADC

LNA

PA

DSP

Antenna to Bits System Design and Modelling
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
WLAN/LTE and beyond…

Evolution of Air Interface Technologies

4G

3GPP LTE, LTE-A

IEEE 802.11 WLAN standards

5G?

Requirements

• Higher data rates
• More flexible spectrum use
• Spatial resource
• Low delay & link adaptability
• Reliable service everywhere

Proposed enabling technologies

• Massive MIMO
• Small Cell, HetNet
• New Modulations
• New Frequency bands
WLAN/LTE

Workflow/Use-cases of wireless designers

Signal Generation

Signal Detection

Packet detected

Packet successfully decoded!

End-to-End Simulations

Measurements

HW & Radio Connectivity

RF Signal Generator  SDR
LTE System Toolbox

- LTE and LTE-Advanced (Rel-8 through **Rel-12**)
- Scope
  - FDD/TDD
  - Uplink/Downlink
  - Transmitter/Receiver
- ~200 functions for physical layer (PHY) modeling
- Signal generation for LTE & UMTS
- ACLR/EVM measurement
- Conformance Tests
LTE System Toolbox | More information...

- Consult LTE Product Page
  - www.mathworks.com/products/lte-system/
  - Provides overview of LTE/LTE-A capabilities
  - Organized based on use-cases

- Consult Wireless Communications Page
  - www.mathworks.com/wireless
  - Provides overview of today’s MATLAB® for Wireless System Design

- For details: Attend Recorded Webinar:
  - “Introducing LTE System Toolbox”
WLAN System Toolbox

- **Physical layer (PHY) modeling**
  Standard-compliant functions for the design, simulation, analysis, and testing of wireless LAN communications systems

- **Transmitter & Receiver**
  - L-SIG, HT-SIG, VHT-SIG-A, VHT-SIG-B
  - OFDM, MIMO Equalization, STBC Combining
  - Packet detection, symbol timing correction
  - Coarse and fine frequency offset estimation
  - Preamble signal decoders for L-SIG, HT-SIG, VHT-SIG-A, VHT-SIG-B fields

- **Propagation Channel**
  - TGn, TGac

- **Measurements**
  - Packet Error Rate, EVM, Spectral Emissions

- **Features**
  - Open, customizable MATLAB code
  - C-code generation with MATLAB Coder
WLAN System Toolbox

*Hardware & Radio Connectivity*

Generate custom waveforms
Transmit with SDR devices or RF instruments
Capture signals with SDR or instruments
Recover original data

Range of supported hardware
- RF Signal Generator
- Spectrum Analyzer
- Zynq Radio SDR
- USRP SDR
Consult WLAN Product Page
- www.mathworks.com/products/wlan-system/
- Provides overview of WLAN capabilities
- Organized based on use-cases

Consult Wireless Communications Page
- www.mathworks.com/wireless
- Provides overview of today’s MATLAB® for Wireless System Design

For details: Attend Recorded Webinar:
- “Introducing WLAN System Toolbox”
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
Image and Video Processing

- Stereo Camera Calibration  \( R_{2014b} \)
  - Lens distortion correction
  - Rectification
- Depth estimation  \( R_{2014a} \)
- 3D Scene reconstruction  \( R_{2014a} \)
- Code generation  \( R_{2015a} \)
Enables autonomous systems to **map and measure** the world

Supports workflows for **ADAS**, autonomous driving, and robotics

New functionality to support:
- 3D **point cloud** processing
- Structure from motion
Perform fast, accurate image classification

Enables recognition workflows in autonomous robotics and ADAS

Convolutional neural network (CNN) algorithm added to Neural Network Toolbox

Uses cuDNN (a GPU-accelerated library from NVIDIA) (requires Parallel Computing Toolbox)
Signal Processing
Audio
Antenna to Bits
WLAN/LTE
Image and Video Processing
That’s, what’s new!