What’s New in MATLAB and Simulink for Signal Processing

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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

\begin{verbatim}
k = 20;
max = 40;
\end{verbatim}

\begin{verbatim}
for k=1:max;
xFFT = fft(x);
xfft = abs(x);
\end{verbatim}

Analyze data

write MATLAB code.
Signal Processing Engineers...

Model systems

Run simulations

build Simulink models.
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>chol</td>
</tr>
<tr>
<td>conv</td>
</tr>
<tr>
<td>fft</td>
</tr>
<tr>
<td>ifft</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>
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<tr>
<td>iift</td>
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</tbody>
</table>

Signal Processing Toolbox

<table>
<thead>
<tr>
<th>Signal Processing Toolbox</th>
<th>C and C++ code generation for the following functions</th>
</tr>
</thead>
</table>

DSP System Toolbox

<table>
<thead>
<tr>
<th>DSP System Toolbox</th>
<th>C code generation for the following functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>dsp.BurgAREstimator</td>
<td></td>
</tr>
<tr>
<td>dsp.BurgSpectrumEstimator</td>
<td></td>
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<tr>
<td>dsp.CepstralToLPC</td>
<td></td>
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<tr>
<td>dsp.CrossSpectrumEstimator</td>
<td></td>
</tr>
<tr>
<td>dsp.LevinsonSolver</td>
<td></td>
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<tr>
<td>dsp.LPCToCepstral</td>
<td></td>
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<tr>
<td>dsp.LPCToAutocorrelation</td>
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<tr>
<td>dsp.LPCToLPC</td>
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<tr>
<td>dsp.LPCToLSF</td>
<td></td>
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<tr>
<td>dsp.LPCToLSP</td>
<td></td>
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<tr>
<td>dsp.LPCToRC</td>
<td></td>
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<tr>
<td>dsp.LSFToLPC</td>
<td></td>
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<tr>
<td>dsp.LSPToLPC</td>
<td></td>
</tr>
<tr>
<td>dsp.RCtoAutocorrelation</td>
<td></td>
</tr>
<tr>
<td>dsp.RCToLPC</td>
<td></td>
</tr>
<tr>
<td>dsp.SpectrumEstimator</td>
<td></td>
</tr>
<tr>
<td>dsp.TransferFunctionEstimator</td>
<td></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

```matlab
load('enginerpm.mat','s')
fndchangepnt(s,'Statistic','linear','MinThreshold',var(s))
```

**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

```matlab
load clocks
x = s(3640); y = NaN
fillgaps(x)
```

**Dynamic Time Warping**
Stretch, align and compare signals with different time scales
- Compare and align trajectories between two signals in space
- Obtain a measure of similarity of two signals trajectories
- Optional time alignment
- Popular distance metrics supported
  - Euclidean
  - Squared Euclidean
  - Manhattan
  - Symmetric Kulback-Leibler

```matlab
x = chirp(0:499,0,1000,1/100); y = cos(2*pi*5+0:199)/200);
plot(x,y)
```

**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
MATLAB algorithm → Early validation (listening tests) → Advanced prototyping or production

Audio System Toolbox
Prototyping for product development
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

- Phased Array System Toolbox
- Communications System Toolbox

Algorithms
beamforming, beamsteering, MIMO

- Phased Array System Toolbox
- Instrument Control Toolbox

Waveforms
Antenna to Bits
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Antenna to Bits System Design and Modelling
Antenna to Bits

*System Design and Modelling*

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![Antenna Diagram](image-url)
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
From antenna element to antenna array…
Phased Array System Toolbox
Array Antenna Design

```matlab
>> 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];
```
Many phase shifters in real systems are quantized.

Allow customer to quickly see the effect of phase shifter quantization.
Antenna to Bits

System Design and Modelling

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

- Antenna Toolbox
- Phased Array System Toolbox
Antenna to Bits

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RF Impairments

frequency dependency, non-linearity, noise, mismatches

- 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

- Estimation of direction of arrival
- RF phase shifting
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

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

5G standardization

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 successfully decoded!

Packet detected

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

USRPR SDR
WLAN System Toolbox | More information…

- Consult WLAN Product Page
  - Provides overview of WLAN capabilities
  - Organized based on use-cases

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Image and Video Processing

- Stereo Camera Calibration  \textit{R2014b}
  - Lens distortion correction
  - Rectification

- Depth estimation \textit{R2014a}

- 3D Scene reconstruction \textit{R2014a}

- Code generation \textit{R2015a}
Image and Video Processing | Stereo Vision

- 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)
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That’s, what’s new!