Modelling and Prototyping Signal Processing and Communications Systems

Graham Reith
Industry Manager: Communications, Electronics & Semiconductors

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Session Outline

- Part 1 – Algorithm Development
  - Developing signal processing algorithms with relevant toolboxes

- Part 2 – System Modelling
  - Simulating algorithms with real-world implementation effects

- Part 3 – Prototyping Systems and SDR Platforms
  - Developing prototypes to test with real-world signals
Workflow to go from an idea to a product can be broken into 5 activity types:

- Algorithm Development
- System Design
- Prototyping
- Implementation
- Verification

Aim to establish a natural connection between all these different stages in the product development workflow
- Enables new ideas to flow from concept into the product, without undue hindrance
- Promotes innovation and enables agility
MATLAB Example: Parametric Audio Equalizer

- **Audio Input**: Guitar10min.ogg
- **Custom Audio Algorithm**: Parameter Equalizer Filters
- **Create it**: Tunes parameters in real-time
- **Tune it**: MIDI Control
- **See it**: Array Plot
- **Hear it**: Speaker
- **Visualize audio waveforms in real-time**
Introducing System Objects

- 2 Entry Points for describing Signal Processing operations in MATLAB:
  - Data analysis
  - Algorithm exploration
  - System simulation
  - Efficient implementation

[Functions]

```matlab
%Apply filter to data all at once
output = filter(b,a,data);

%Or, save and restore state each call
[output,state] = filter(b,a,data,state);
```

[System Objects]

```matlab
%Instantiate filter with coefficients
Hf = dsp.FIRFilter('Numerator',b);

%Process data through filter
output = step(Hf,data);
```
Challenges in Signal Processing System Design

**Framework for Real-Time Simulations**

“I have to process large data and test my simulations with streaming signals. I need a simulation testbench that can keep up with real-time data.”

**Quick Innovation & Modelling**

“I need to find innovative algorithms and create and model a working system very quickly.”

**Rapid Prototyping & Simulation Acceleration**

“I need to optimize my high-level MATLAB algorithm for speed. I then need to verify that the optimized code works the same way as the original MATLAB code.”
I have to process large data and test my simulations with streaming signals. I need a simulation testbench that can keep up with real-time data.

Framework for Real-Time Simulations
Stream processing technique and hardware peripheral access that speeds up simulation and reduces memory footprint

Quick Innovation & Modelling
Pre-defined algorithms as functions and System Objects for quick prototyping

Rapid Prototyping & Simulation Acceleration
Support for C/C++ code generation that enables design continuity and faster simulation

I need to find innovative algorithms and create and model a working system very quickly.

I need to optimize my high-level MATLAB algorithm for speed. I then need to verify that the optimized code works the same way as the original MATLAB code.
Design and simulate phased array systems
Applications in RADAR, Communications, and Audio

- Arrays, waveforms, targets, clutter, etc...

- Signal processing algorithms
Example: FMCW RADAR

- Antenna Array Analysis
- Simulation of Signal Processing
Progression from Algorithms to Systems

- Initial focus on ‘what’ the algorithm should be
- Then need to consider ‘how’ it should be implemented
  - Fixed-Point, analog vs digital methods
  - Architecture trade-offs, implementation cost
- Requires collaboration between different teams to gain insight, share experience
- System Modelling provides mechanism for collaboration across different teams
Modelling from Antenna to Bits

Antenna, Antenna arrays
- type of element, # elements, configuration

Antenna Toolbox
Phased Array System Toolbox

Communications System Toolbox
LTE System Toolbox
Phased Array System Toolbox

Channel
- interference, clutter, noise

Mixed-Signal
Continuous & discrete time

Simulink (Simscape)
DSP System Toolbox
Control System Toolbox

Algorithms
beamforming, beamsteering, MIMO

Phased Array System Toolbox
DSP System Toolbox
Communications System Toolbox
LTE System Toolbox

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

SimRF
RF Toolbox

Waveforms

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Example: AD9361 Simulation Model

- Predict the impact of RF Imperfections in test signals
- Use reference tones and LTE Signals
- Evaluate the effects of nonlinearity, noise, gain and phase imbalance
- Generate AD9361 configuration file
LTE System Toolbox

- Standard-compliant models for LTE and LTE-Advanced
- End-to-end physical layer transmit and receive processing functions
- Test models and reference measurement channel waveform generators
Model-Based Design
A single shared development environment
Model-Based Design
A single shared development environment

Verify operation in simulation

Validate performance with live signals

Deploy design on production system
Radio Prototyping Hardware Support

- **RTL-SDR**
  - Ultra low-cost, low-bandwidth
  - Rx Only

- **USRP**
  - Customizable RF front-end

- **Xilinx FPGA-based radio**
  - High bandwidth (~25MHz)
  - Possible FPGA target

- **Spectrum Analyzers**
  - High-quality RF front-end
  - Wide frequency range, high bandwidth
  - Higher cost
Example: RTL-SDR USB RF Receiver

\[
\begin{align*}
\text{Sampling frequency} & \quad \text{(up to } \sim 2.8\text{MHz}) \\
\text{RF Centre Frequency} & \quad \text{(20MHz to } \sim 1.8\text{GHz}) \\
+ & \quad \text{Tuner gain parameters} \\
& \quad \text{Frequency correction parameters}
\end{align*}
\]
Raspberry Pi with RTL-SDR

- New in R2015b: Using the Raspberry Pi with the RTL-SDR receiver
- Deploy signal processing algorithms directly to the ARM processor on the Raspberry Pi, and stream in data from the RTL-SDR receiver
- Output audio, or send data to ThingSpeak, etc
Exhibition: Using SDR Platforms for Communications Prototyping

- Transmit and receive live image / audio on 4G LTE signals using Zynq based Software Defined Radio (SDR) and LTE System Toolbox
- Model the AD9361 RF chip used on the SDR platform
Xilinx FPGA-Based Radio: SDR Peripheral

- Execute fixed radio functions on FPGA
- Tunable pre-defined radio parameters
Xilinx FPGA-Based Radio: SDR Target

- Generate HDL code to implement custom radio functionality on FPGA
Production Integration

Simulation
- Simulink
  - Algorithm Model
- Algorithm Model

Prototype
- ARM
  - Algorithm C
  - Linux Driver
  - AXI Bus
  - AXI Interface
  - Algorithm HDL

Production
- ARM
  - Algorithm C
  - Linux Driver
  - AXI Bus
  - AXI Interface
  - Algorithm HDL
  - IP1
  - IP2
  - IP3
Review: Workflow for Signal Processing Product Development

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