MATLAB for Verification and Analysis of Communications

Darel A. Linebarger, Ph.D.
Senior Manager, Communications and Signal Processing
MathWorks, Inc.
Observations about testing and verification

- Many groups report that more time and energy is spent in testing and verification than in design and develop.
- It’s not sexy, but it’s important 😊.
  - Great candidate for “work smarter, not harder”
- Thoughts:
  - Test as you go. Waiting to test until the whole thing is built is guaranteed failure (or at least guaranteed to take longer). So build a little, test a little.
  - Great value in having a “golden reference”. Allows you to keep yourself on track.
  - Realistic test vectors crucial to success of final product.
  - Best engineers “own” testing AND design, even if there is another person in the official role of testing.
Verify your MATLAB/Simulink based phy layer design: A proposed package:

- Waveform generators
- Channel models
- A basic receiver
- Connectivity to test equipment and real world I&Q
- Visualization (scopes) and analysis
- Library of components and modules
- Lastly, make this package standard specific where appropriate

- Let us help with boring part while you focus on your key deliverables
- Would you buy it? If so, for which standards?
Verify your MATLAB/Simulink based phy layer design: A proposed package (more details):

- **Waveform generators**
  - Flexible, fully featured standard specific transmitter
  - Can feed directly to receiver or over the air

- **Channel models**
  - Standard specific, accurate and fast
  - Configurable to defined scenarios as described in standard

- **A basic receiver**
  - Not the one you will ship, but helpful as a starting point
  - Just the data processing, perhaps no sync

- **Tools and support for measuring BER, throughput, etc.**
Verify your MATLAB/Simulink based phy layer design: A proposed package (more details):

- Connectivity to test equipment and real world I&Q
  - Easy access to professional T&M gear for testing and debugging
  - Easy access to real world I&Q for testing and debugging
  - Easy access to other I/O such as audio, network, files, etc. (E.g. audio output is great feedback if transmitting speech or music)

- Scopes and analyzers provide immediate visual feedback
  - Constellation, eye diagram, spectrum analyzer, time scope, logic analyzer, etc.
  - Provide standards specific measurements for items such as EVM, ACPR, CCDF, MER
  - Make BER easy and fast – use multi-core (using Parallel Computing Toolbox)

- Rich library of components and modules to assist you in debugging your system or to provide a starting point
  - Mix and match our components with yours to speed development and debugging
Two categories of support: (1) strictly I/O or (2) I/O AND targetable

Strictly I/O
- RTL-SDR
- ZedBoard coming

Supports targeting (FPGA) and I/O
- USRP N now, B and X coming
- Xilinx ML605 now, Zynq ZC706 coming

Show in product demo for LTE and T&M gear
## SDR Platforms Now

<table>
<thead>
<tr>
<th>PLATFORM</th>
<th>Frequency Range</th>
<th>BW</th>
<th>A/D</th>
<th>Target device</th>
<th>Applications</th>
<th>Price</th>
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<tbody>
<tr>
<td>RTL-SDR (NESDR)</td>
<td>30MHz - 1.8GHz</td>
<td>~2MHz</td>
<td>7-bit, 2.8MSps</td>
<td>None</td>
<td>FM, DAB, DVB, GPS</td>
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<tr>
<td>USRP N200 Basic TxRx</td>
<td>see daughterboards below</td>
<td>16-bit, 25 Msps</td>
<td>Spartan 3A-DSP 1800</td>
<td>FM, DAB, DVB, GPS</td>
<td>$1,500</td>
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<tr>
<td>USRP N210 Basic TxRx</td>
<td>see daughterboards below</td>
<td>16-bit, 25 Msps</td>
<td>Spartan 3A-DSP 3400</td>
<td>FM, DAB, DVB, GPS</td>
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<tr>
<td>USRP - CBX (RxTx) (daughterboard)</td>
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<td>40 MHz</td>
<td>14 bit sign extended 1o</td>
<td>Virtex 6</td>
<td>FM, DAB, DVB, GPS</td>
<td>$475 (additional)</td>
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<tr>
<td>USRP - SBX (RxTx) (daughterboard)</td>
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<td>40 MHz</td>
<td>16 bits, 5MHz to 105MHz</td>
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<td>FM, DAB, DVB, GPS</td>
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<td>40 MHz</td>
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<td>FM, DAB, DVB, GPS</td>
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<td>330KHz to 28MHz</td>
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<td>FM, DAB, DVB, GPS</td>
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<td>ADI FMCOMMS1 RevB</td>
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<td>Virtex 6</td>
<td>FM, DAB, DVB, GPS</td>
<td>$2500 (additional)</td>
</tr>
</tbody>
</table>
Speedup with Multicore CPUs & Clusters
Parallel Computing Toolbox & MATLAB Distributed Computing Server

Desktop Computer

Local

MATLAB Desktop (Client)

Computer Cluster

Cluster

Scheduler

TS36.101 Test 12: R.7 1x2 ETU 70Hz

Throughput (%) vs SNR (dB)

simulated

target
Connecting to T&M Instruments
Instrument Control Toolbox

Signal Generation and Transmission

- Generate LTE baseband signal in MATLAB
- Download to Signal Generator
Connecting to T&M Instruments
Instrument Control Toolbox

Signal Acquisition and Analysis

- Retrieve IQ data into MATLAB for analysis
- Perform visualization and analysis in MATLAB

PDCCH search for SI-RNTI...
Decoding SIB1...
SIB1 CRC: 0
Successful SIB1 recovery.
Demos

- **Three categories:**
  - New easy to use, inexpensive RTL hardware
  - LTE systems
  - WiFi (802.11)
  - All of above with T&M gear and/or real world signals on the air

- **Demos:**
  - FM demod using RTL-SDR
  - Spectrum Analyzer using RTL-SDR
  - 802.11 beacon decode using Xilinx ML605
  - LTE waveform generation
  - LTE Downlink Channel Estimation and Equalization
  - Connect LTE System Toolbox to Agilent VSA
RTL-SDR Support Package

RTL-SDR Support from Communications System Toolbox

The RTL-SDR radio support package enables you to design wireless receivers using real world signals. Using Communications System Toolbox™ in conjunction with an RTL-SDR USB radio, you can design and prototype systems that process real-time wireless signals in MATLAB® and Simulink®. Wireless engineers, students, and hobbyists can learn to receive and decode real-world radio signals using this low-cost RTL-SDR hardware connected to your computer.

Key Features:
- RTL-SDR radio as an I/O peripheral to receive streaming RF signals
- Configurable center frequency and sample rate
- NooElec™ NESDR Mini USB Stick (R820T) and NooElec NESDR Nano USB Stick (R820T) SDR devices with frequency range 30kHz – 1.0GHz
- Compatible with other RTL-SDR/USB radios (e.g., Terratec T-Box E4000)
- Several application examples for getting started:
  - FM Mono / Stereo with RTL-SDR
  - FRS Receiver with RTL-SDR
  - Spectral analyser with RTL-SDR
  - Frequency offset calibration with RTL-SDR

Get Support Package Now

Support Package Installer

Select support package to install

<table>
<thead>
<tr>
<th>Show:</th>
<th>Support for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (59)</td>
<td>Communications System Toolbox Win32, Win64</td>
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</table>

<table>
<thead>
<tr>
<th>Action</th>
<th>Installed Version</th>
<th>Latest Version</th>
<th>Required Base Product</th>
<th>ported Host Platform</th>
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<td>14.1.0</td>
<td>Communications System Toolbox</td>
<td>Win32, Win64</td>
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</table>

Installation folder: C:\MATLAB\Support\Packages\RTLSDR
The RTL-SDR USB RF Receiver

Configuring SDR parameters (via USB port)

- $f_{RF}$ - RF Center frequency
- $f_s$ – I/Q Data Sampling Frequency
- Gain Control Parameters
- Frequency Correction
An *IF* Software Defined Radio

(IF – Intermediate Frequency)

Raphael Micro R820T Silicon Tuner

**Analogue**

- RF Antenna
- LNA
- RF Filter
- IF Filter
- AGC
- VCO

NooElec SDR Mini Receiver

- RF VCO Frequency (50MHz to 1.4 GHz)
- Tuner Gain Control
- Voltage Controlled Oscillator

RTL2832U – Digital IF to Baseband Receiver

**Digital**

- Low Pass FIR Filter + Decimation
- Re-Sampler/ Synch.
- NCOs
- Re-Sampler/ Synch.
- Low Pass FIR Filter + Decimation

- I/Q Data sampling frequency (up to 2.8MHz)
- Sampling rate of ADC (28.8MHz)
- Analogue to Digital Converter
- In-phase & Quadrature-phase Channel
- Finite Impulse Response
- Numerically Controlled Oscillator

**Notation**

- $f_{RF}$: RF VCO Frequency
- $f_a$: Sampling rate of ADC
- $f_s$: I/Q Data sampling frequency
- ADC: Analogue to Digital Converter
- I/Q: In-phase & Quadrature-phase Channel
- FIR: Finite Impulse Response
- NCO: Numerically Controlled Oscillator

**MathWorks**

- IF – Intermediate Frequency
- SDR: Software Defined Radio
- LNA: Low Noise Amplifier
- AGC: Automatic Gain Control
- VCO: Voltage Controlled Oscillator
- ADC: Analogue to Digital Converter
- NCO: Numerically Controlled Oscillator
And what RF signals can we find?

- **FM Radio**: 87.5 – 108 MHz
- **Aeronautical**: 108 – 117 MHz
- **Meteorological**: ~ 137 MHz
- **Fixed mobile**: 140 – 150 MHz
- **Special events broadcast**: 174 – 217 MHz
- **Fixed mobile, (space to Earth)**: 267 – 272 MHz
- **Fixed mobile, (Earth to space)**: 213 – 315 MHz
- **ISM band (short range)**: ~433 MHz
- **Emergency services**: 450 – 470 MHz
- **UHF TV Broadcasting**: 470 – 790 MHz
- **Fixed mobile telephony**: 862 – 890 MHz
- **GSM-R band (UK)**: 921 – 925 MHz

*Parameters from Simulink (via USB port)*

- $f_{RF}$ – RF Center frequency
- $f_s$ – Sampling Frequency
- Gain Control Parameters
- Frequency Correction

(Remember to get a good antenna for signal frequencies you seek! And frequencies vary by country?)
FM Broadcast Signals (from Wikipedia)
FM Demodulation of on-air signals

- Message is instantaneous frequency of transmitted signal
  - Integrate instantaneous frequency to get instantaneous phase for transmission
- To demod, differentiate instantaneous phase of received signal
What’s the LTE System Toolbox?

- Release 8, 9 and 10 (LTE-A)
- Scope
  - TDD/FDD,
  - Uplink/Downlink
  - Transmitter/Receiver
- ~200 functions for physical layer (PHY) modeling
- Link-level simulation
  - No C/HDL code generation
- Conformance Tests
Signal Generation and Analysis Reference Measurement Channels

Standard-compliant signal available in the MATLAB workspace

TS 36.101

 LTE DL RMC Generator

Generate Downlink Reference Measurement Channel (RMC) waveforms for the Physical Downlink Shared Channel (PDSCH) performance requirements (specified in TS 36.101 A3).
Standard-Compliant Solution

- Tested against instrument-generated signals
  - Rohde & Schwarz
  - Agilent

- Used in the industry since 2009
  - Initially under Steepest Ascent
  - MathWorks acquired Steepest Ascent

- Successfully demodulates live LTE signals captured in the field
Typical Use Cases for LTE System Toolbox

- Golden reference to verify in-house PHY models
- Complete end-to-end link-level simulation
- Signal generation and analysis (Test and verify)
- Signal information recovery
Test an 802.11 Beacon Receiver with Off-Air Data

- Problem – build an 802.11 beacon receiver without committing to hardware
  - Use a real WiFi signal
  - Model the receiver in software
  - Need connectivity between the WiFi router and your host computer

- Let’s go to the model
Test an 802.11 Beacon Receiver with Off-Air Data (cont.)

- Receive off-air data with an ML605/ADI FMCOMMS1 SDR platform
- For $750, add the analog FMCOMMS1 daughtercard to your ML605 to create a software defined radio platform
- 400 MHz to 4 GHz
- < 125 MHz analog channel bandwidth
- 250 Msps ADC, 1 Gsps DAC
- MIMO capable
Test an 802.11 Beacon Receiver with Off-Air Data (cont.)

- Send data from the ML605 to MATLAB/Simulink with the Communications System Toolbox Support Package for Xilinx® FPGA-Based Radio.
Test an 802.11 Beacon Receiver with Off-Air Data (cont.)
Test an 802.11 Beacon Receiver with Off-Air Data (cont.)

- Tunable center frequency, gain, and A/D sample rate
- Double, single, and int16 support
- Burst mode
Q&A

Thank you!
Getting Started with real time Desktop SDR

- You can order a NooElec RTL-SDR (try Amazon) – less than $20 for the USB mini stick, simple antenna (& postage).

- Then download the RTL-SDR Hardware Support Package from Add-Ons > Get Hardware Support Packages within MATLAB 2013b (or later).
Getting Started with real time Desktop SDR

- After download note the the Communications System Toolbox Support Package for RTL-SDR Radio in the Simulink library browser.

Or type sdrllib at the MATLAB prompt.

- With the RTL-SDR USB and the support package you are now ready explore the radio frequency signals around you with SDR!
MathWorks RTL-SDR Driver (Simulink)

**Sampling frequency (up to 2.8MHz)**

**f_{RF}**  
RF Center Frequency (50MHz to 1GHz)

+ Tuner gain parameters

**Frequency correction parameters**

*Note: You will need MATLAB/Simulink (2013b or later) and (i) Communications Systems Toolbox, (ii) Signal Processing Toolbox and (iii) DSP Systems Toolbox to work with RTL-SDR.*
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