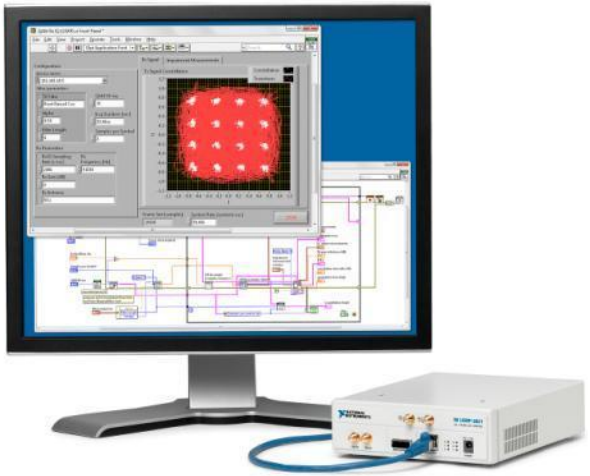
A Rapid Graphical Programming Approach to SDR Design and Prototyping with LabVIEW and the USRP



Sam Shearman
Senior Software Engineer
Communications / Signal Processing
National Instruments

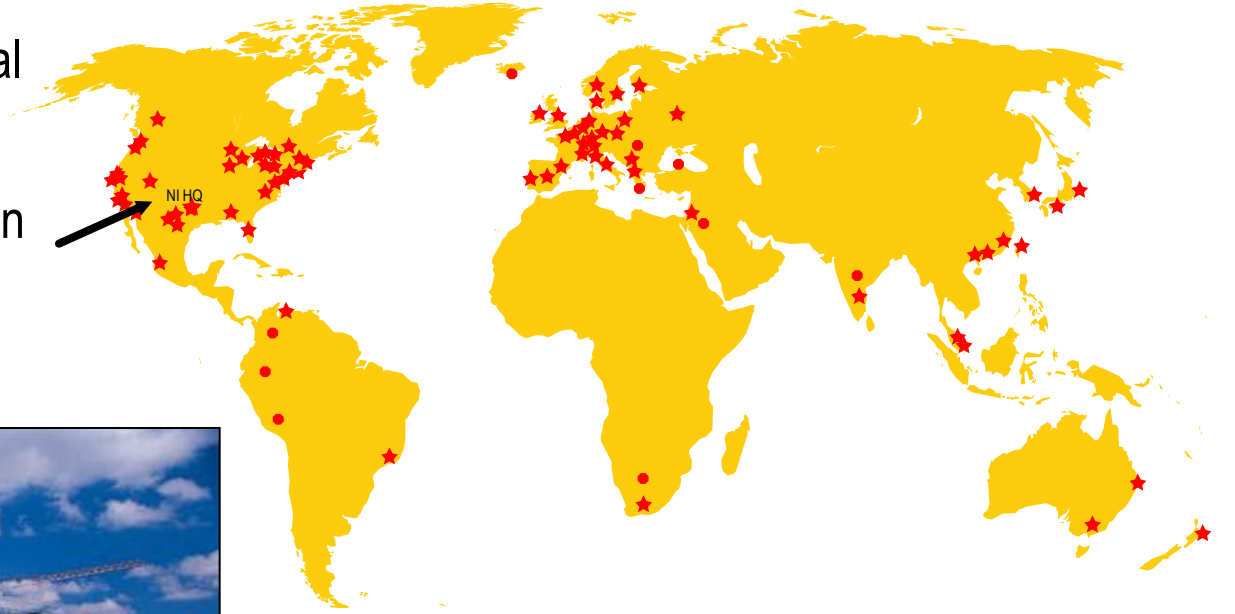
Demo 1

Agenda

- Background
- NI USRP HW / SW Components
- Getting started with NI USRP
- SDR with NI USRP
- Resources

National Instruments

- More than 40 international branches
- Corporate headquarters in Austin, TX



Dr. James Truchard, CEO

- 5,500+ employees
- More than 1,000 products

National Instruments

Offering graphical system design solutions to the Test and Measurement and Industrial Embedded markets

Revenue: $873M revenue in 2010, $253M revenue in Q2 2011

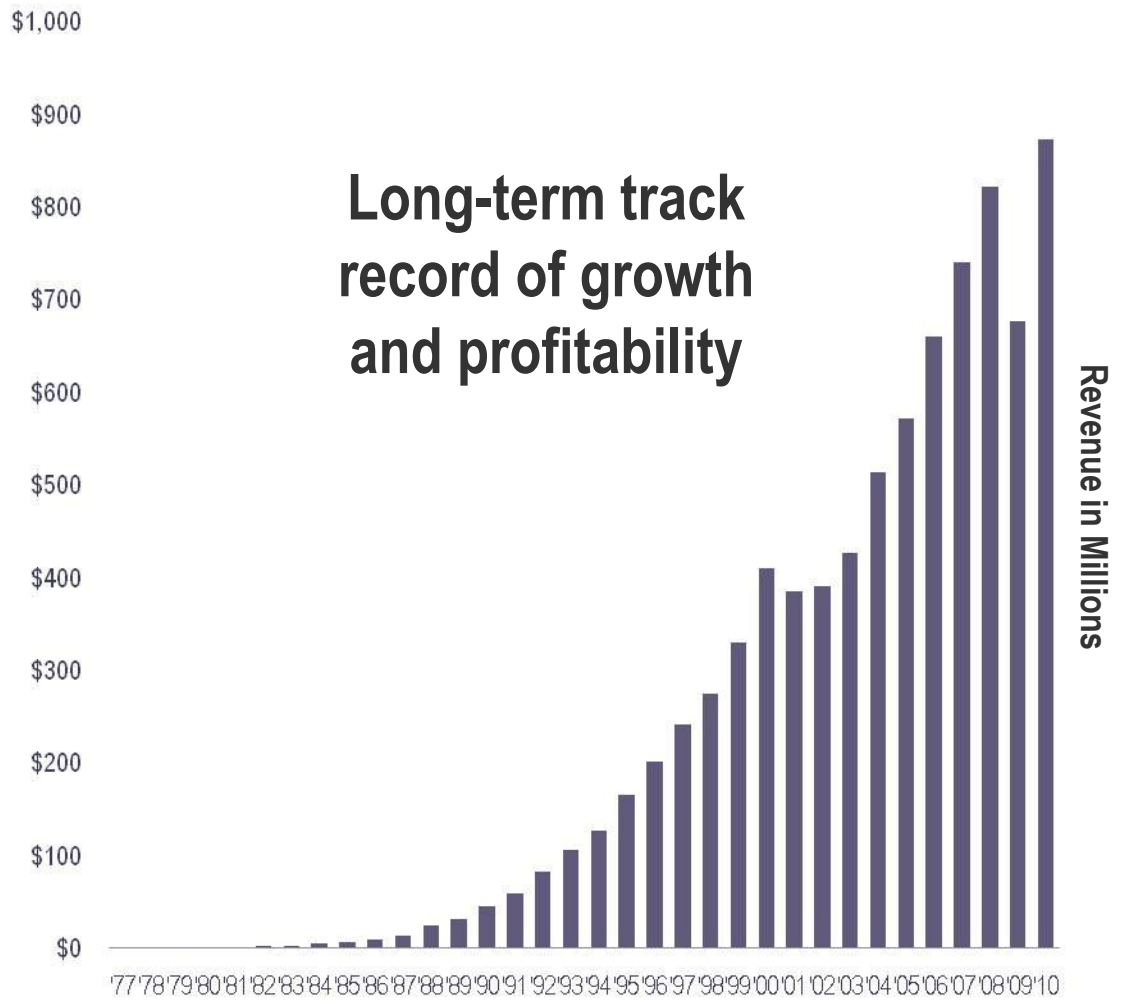
Global Operations: Approximately 5,500 employees; operations in more than 40 countries

Broad customer base: More than 30,000 companies served annually

Diversity: No industry >15% of revenue

Culture: *FORTUNE's* 100 Best Companies to Work For list for 12 consecutive years

Strong Cash Position: Cash and short-term investments of $320M at June 30, 2011



NI-USRP: a Platform for SDR Design, Prototyping and Exploration

- Low cost ($3000), PC-hosted RF Transceiver for software defined radio
- Real-time processing: Gigabit Ethernet link streams live data for real time processing on a host PC running LabVIEW
- Hardware and software are easy to install, connect, and learn

NI-219x
RF Transceiver

NI USRP

Tunable RF Transceiver Front Ends

- Frequency Range
  50 MHz – 2.2 GHz (NI-2920)
  2.4 GHz & 5.5 GHz (NI-2921)

Signal Processing and Synthesis

- NI LabVIEW to develop and explore algorithms
- NI Modulation Toolkit and LabVIEW add-ons to synthesize and process live signals

Applications

- FM Radio
- TV
- GPS
- GSM
- ZigBee®
- Safety Radio
- OFDM
- Passive Radar
- Dynamic Spectrum Access

Gigabit Ethernet Connectivity

- Plug-and-play capability
- Up to 20 MS/s baseband IQ streaming

NI USRP enables Host-based Processing

RF Transceiver

Baseband IQ

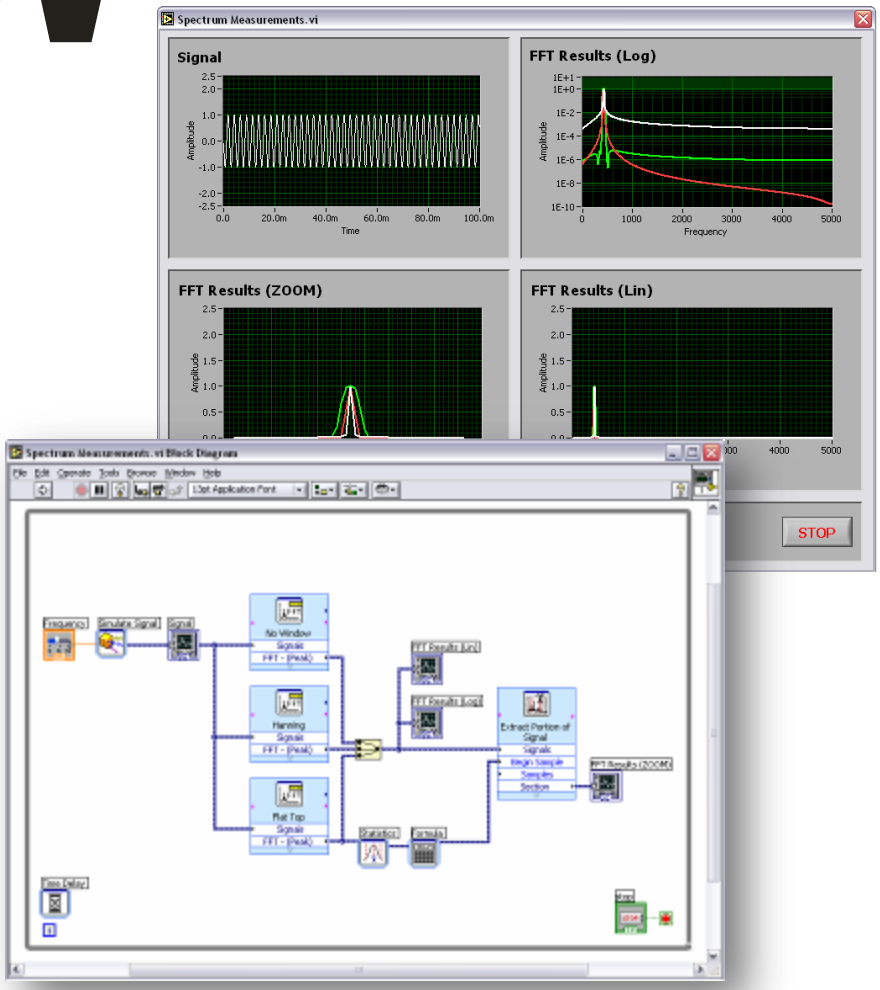
Host-based Processing

NATIONAL INSTRUMENTS™

LabVIEW™

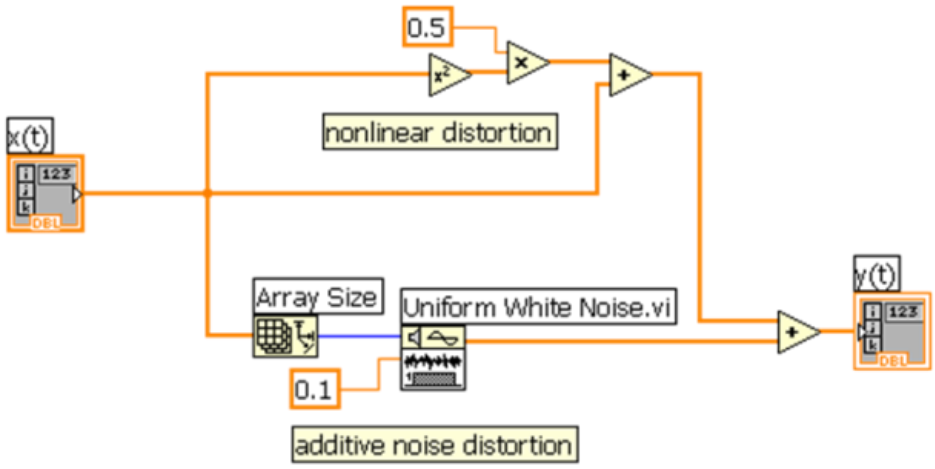
A Compiled Graphical Development Environment

- Intuitive graphical dataflow programming environment with integrated .m file script textual math
- Functionality tailored for science and engineering
- 750+ functions for signal processing, analysis, and mathematics



Graphical Dataflow Programming

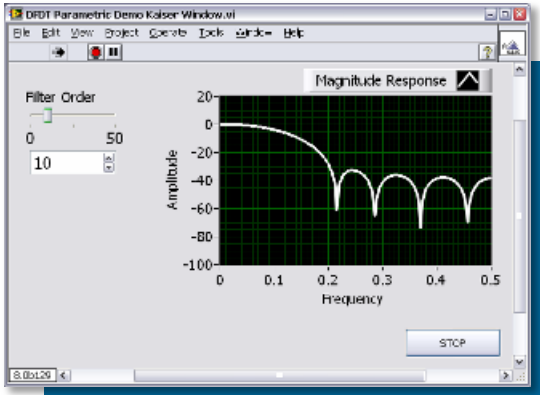
- An intuitive visual representation
- Aligns with algorithm developer's thought process
- Maps functional blocks to concepts with a familiar presentation
- Modular and hierarchical
- High-level tools and building-blocks
- Directly represents parallel, multithreaded, distributed systems

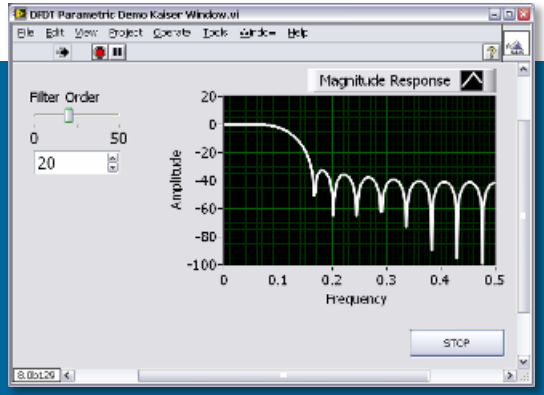


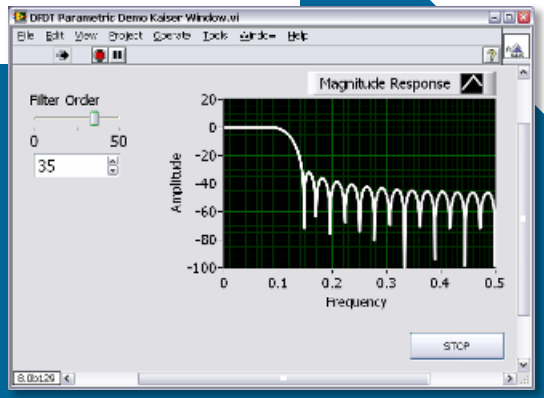
$$y[n] = 0.5x^2[n] + x[n] + 0.1U_n[n]$$

NATIONAL INSTRUMENTS™ LabVIEW™

Interactivity







- Problem Definition
- Concept Demos
- Computational Exploration
- Design
- Interactive Analysis

NATIONAL INSTRUMENTS

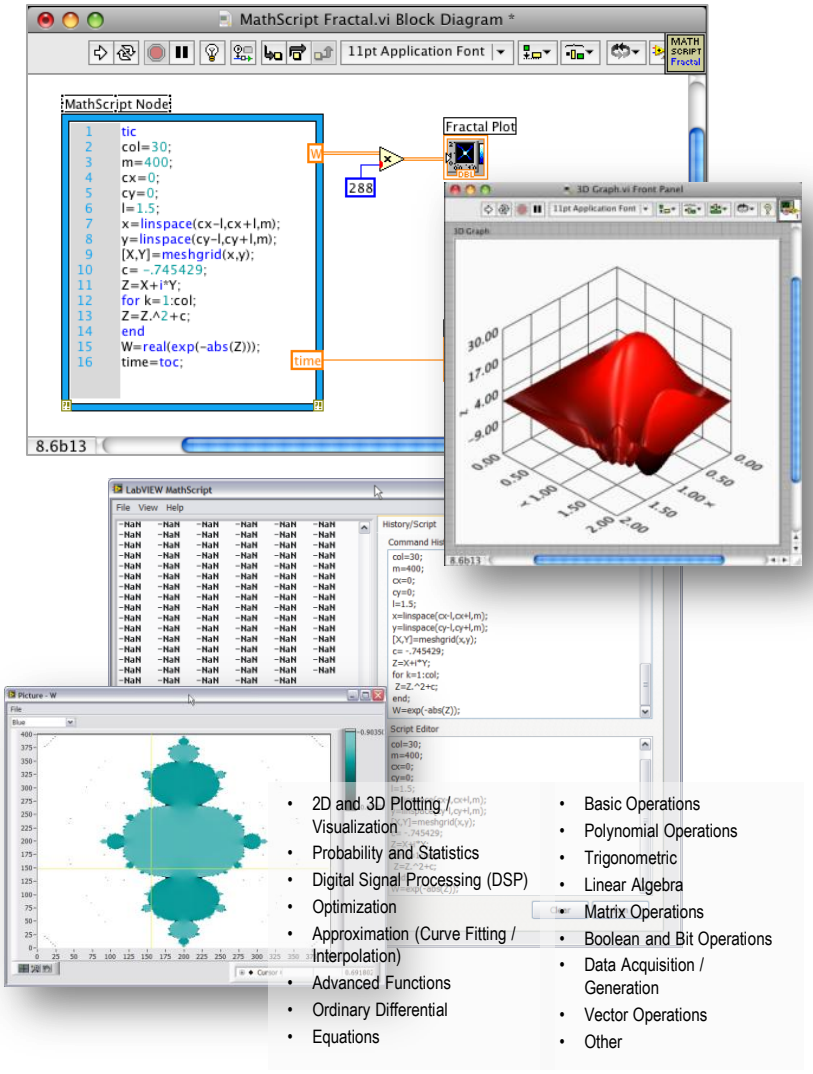
LabVIEW™ MathScript RT Module

Text-based signal processing, analysis, and math within LabVIEW

- 750 built-in functions / user-defined functions
- Reuse many of your .m file scripts created with The MathWorks, Inc. MATLAB® software and others
- Based on original math from NI MATRIXx software

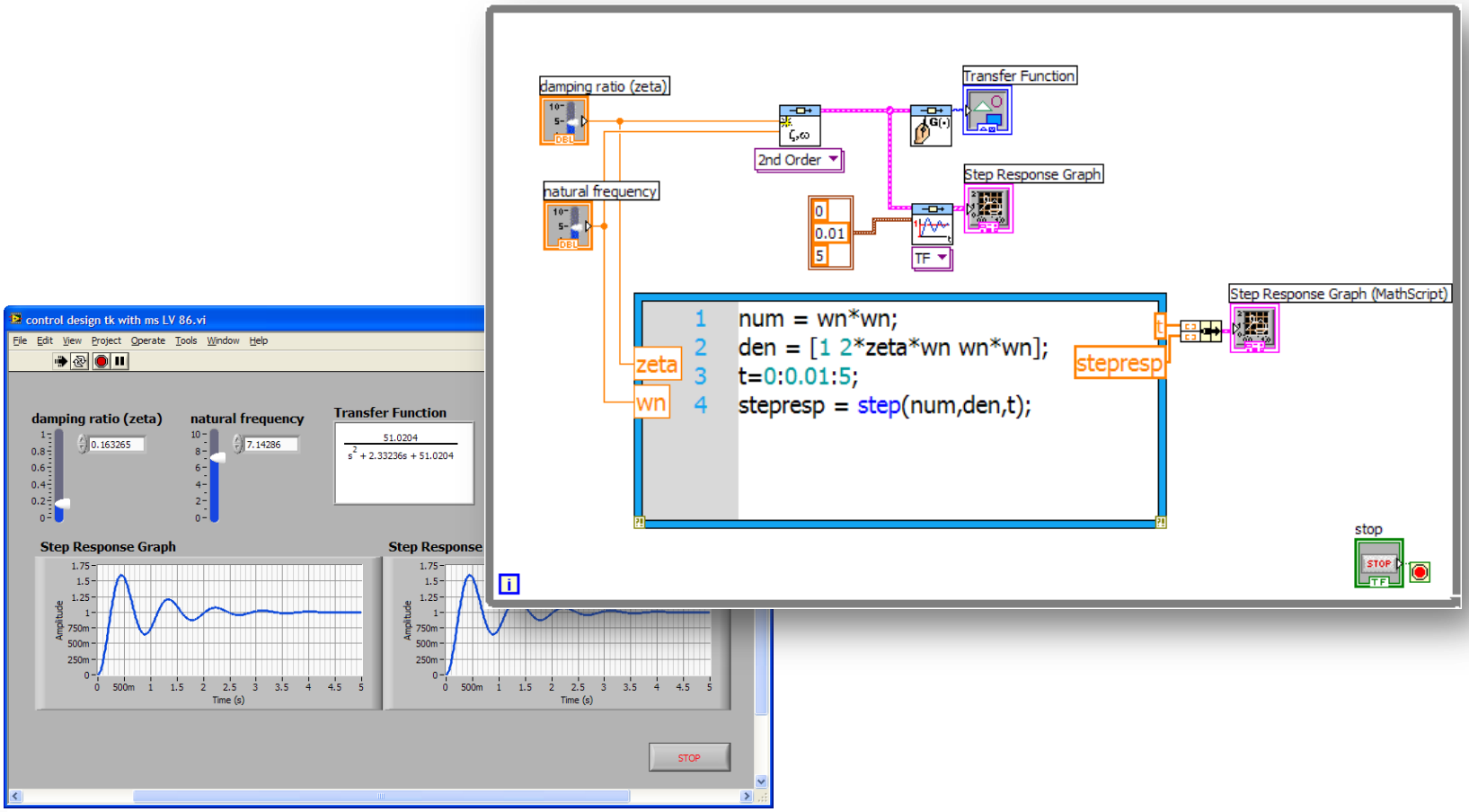
A native LabVIEW solution

- Interactive and programmatic interfaces
- Does not require 3rd-party software
- Enables hybrid programming



The Hybrid Approach

Combine Graphical / Textual Programming



Demo 2a: Simple USRP-based Receiver

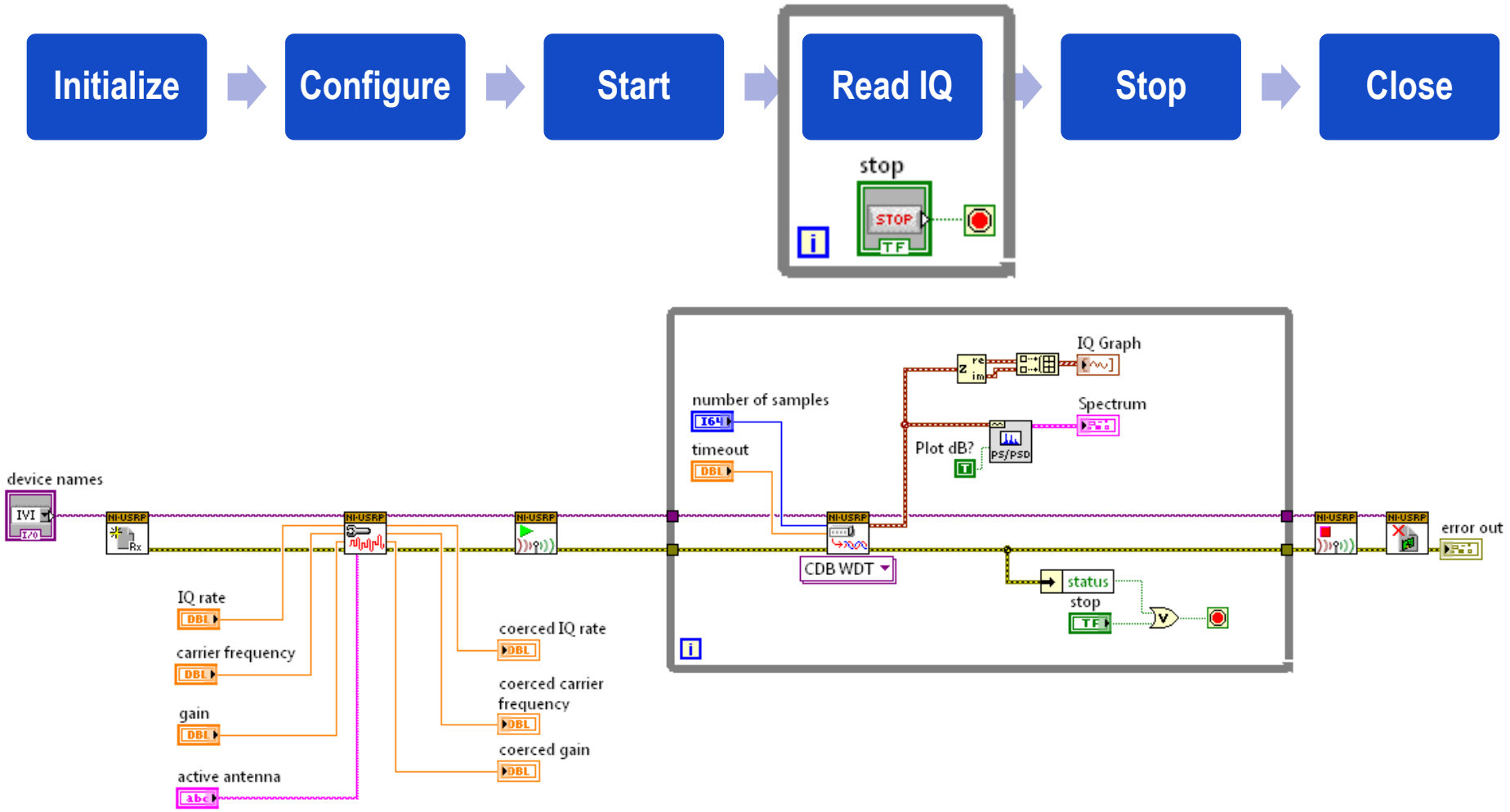
Gigabit Ethernet
Connection to Host Computer

NI USRP-2190
Receiver

NATIONAL INSTRUMENTS LabVIEW

- USRP control (Tx & Rx)
- Inline Processing / Display

NI-USRP Driver Software



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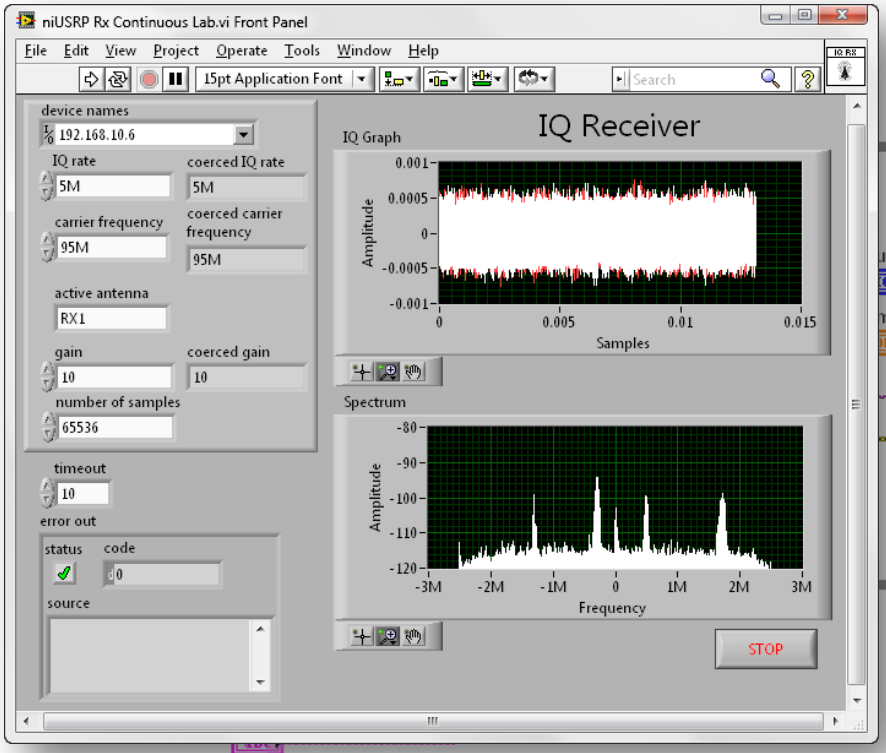
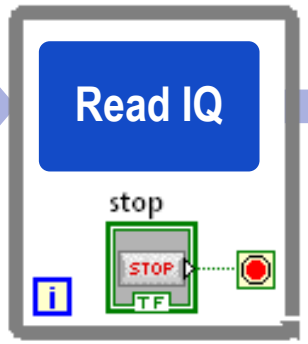
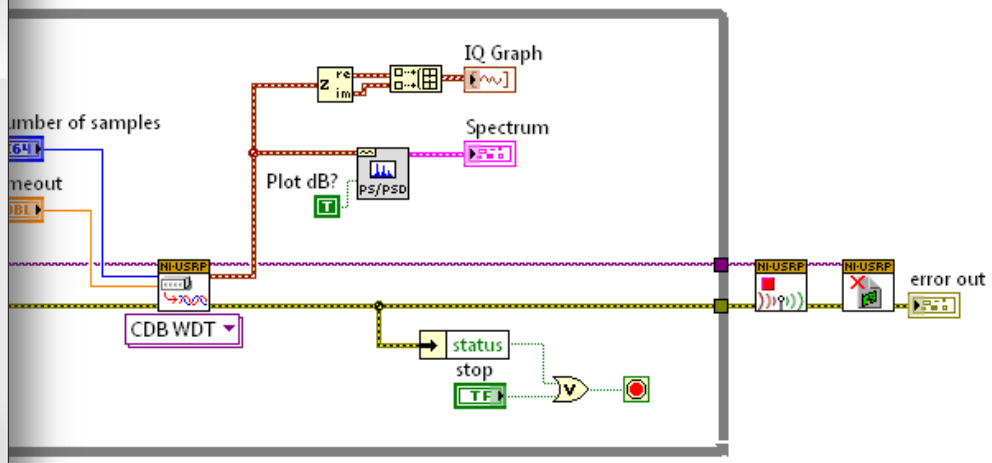
NI-USRP Driver Software

Initialize → Configure → Start → Read IQ → Stop → Close







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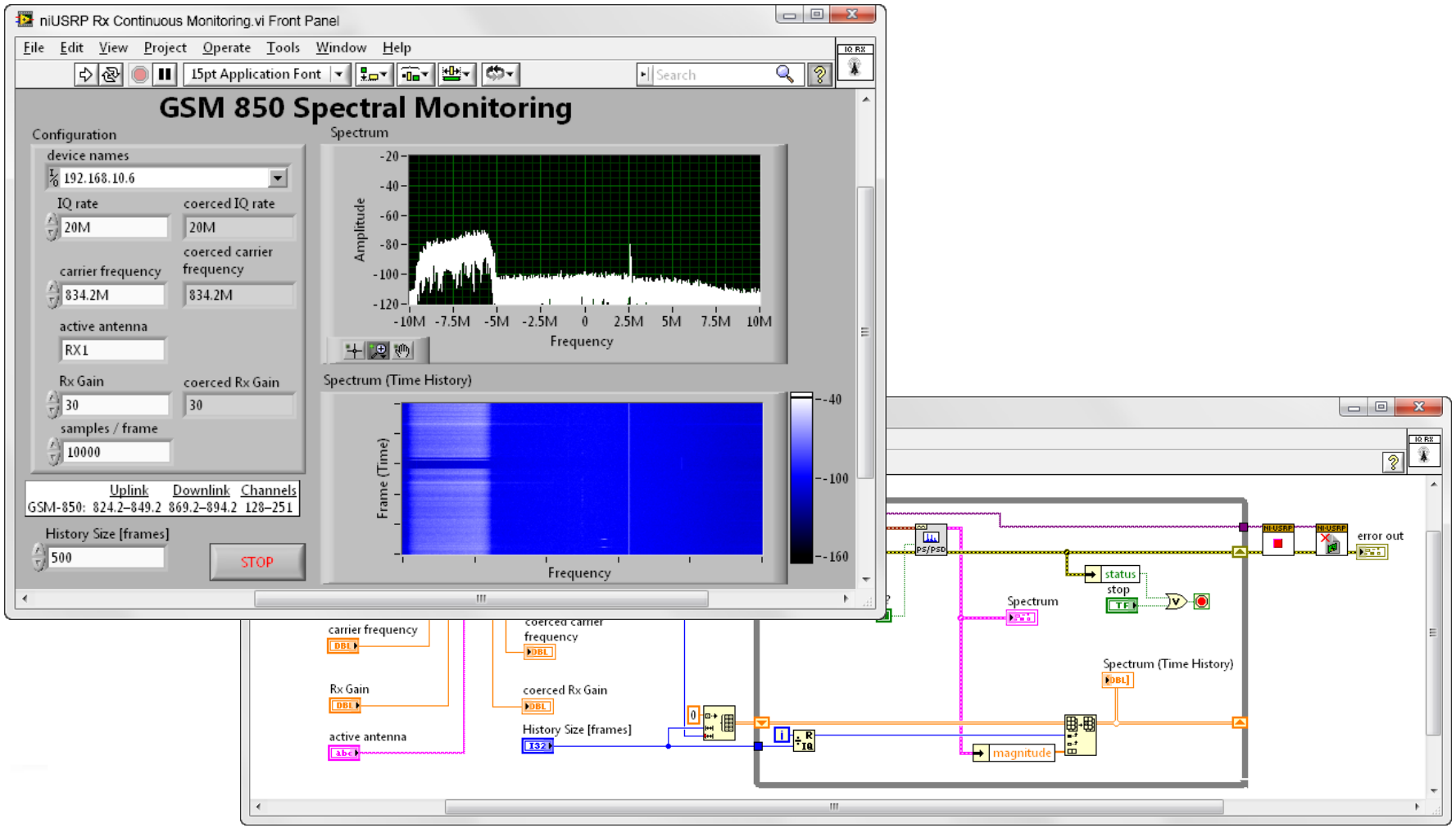
Real-time Spectrum Monitoring



Demo 2b: Simple USRP-based Receiver

- with Spectrum Analysis

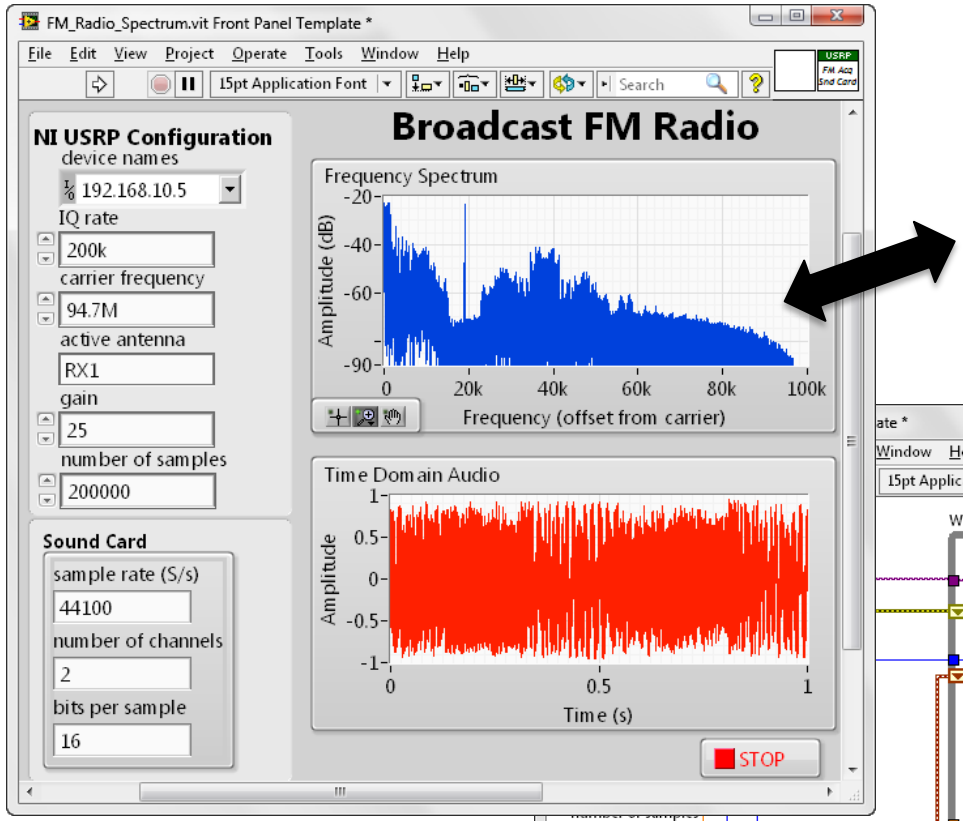
Gigabit Ethernet
Connection to Host Computer

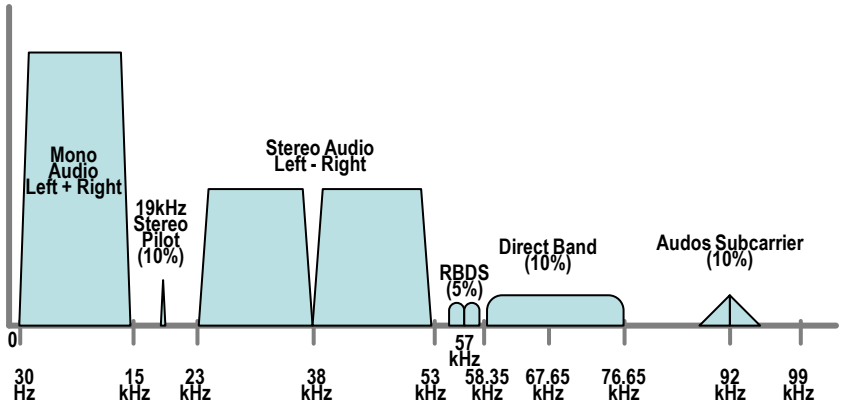
NI USRP-2190
Receiver

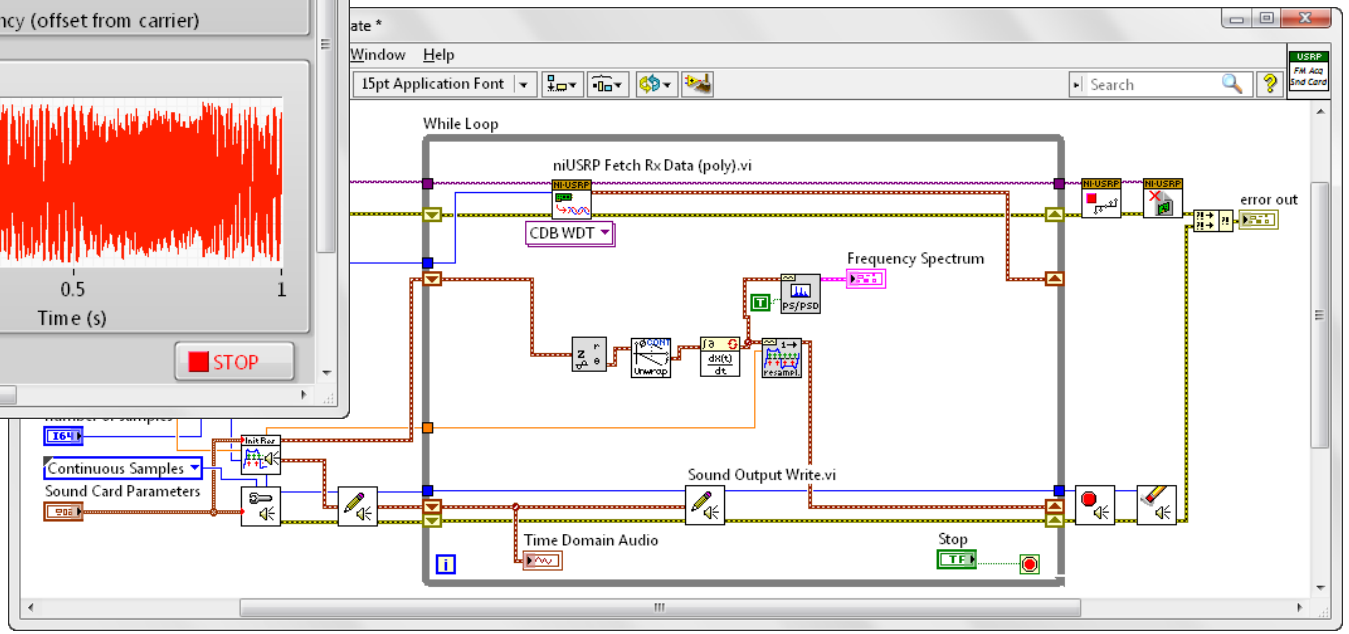
NATIONAL INSTRUMENTS LabVIEW

- USRP control (Rx)
- Inline Processing / Display

Decode & Hear Live FM Radio







Demo 2c: Simple USRP-based Receiver

- with Spectrum Analysis
- with live FM radio

NI USRP-2190
Receiver

Gigabit Ethernet
Connection to Host Computer

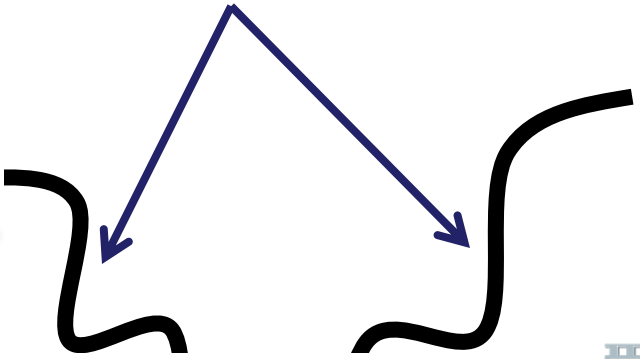
NATIONAL INSTRUMENTS LabVIEW

- USRP control (Rx)
- Inline Processing / Display

Demo 3: Simple USRP-based Transmitter

NI USRP-2190
Transmitter

Gigabit Ethernet
Connections to Host Computer

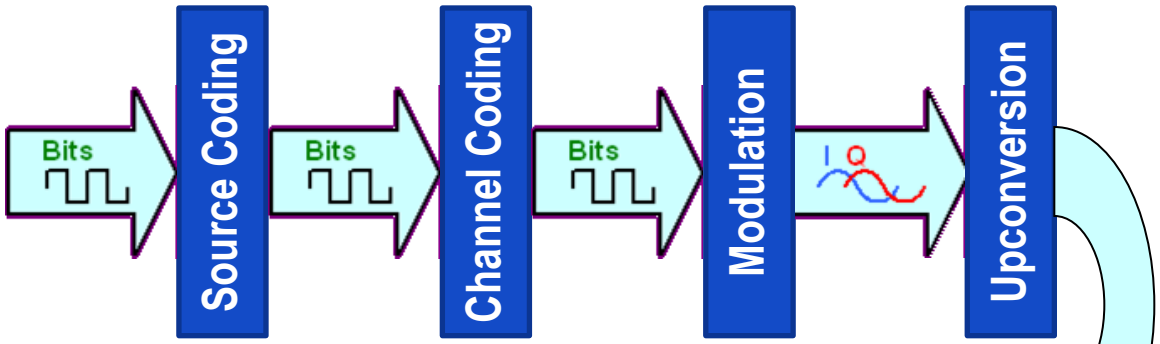


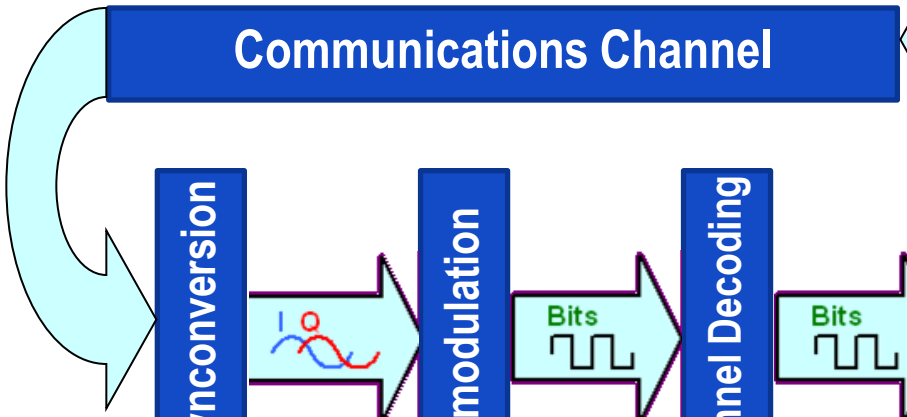
NI USRP-2190
Receiver

NATIONAL INSTRUMENTS LabVIEW™

- USRP control (Tx/Rx)
- Inline Processing / Display

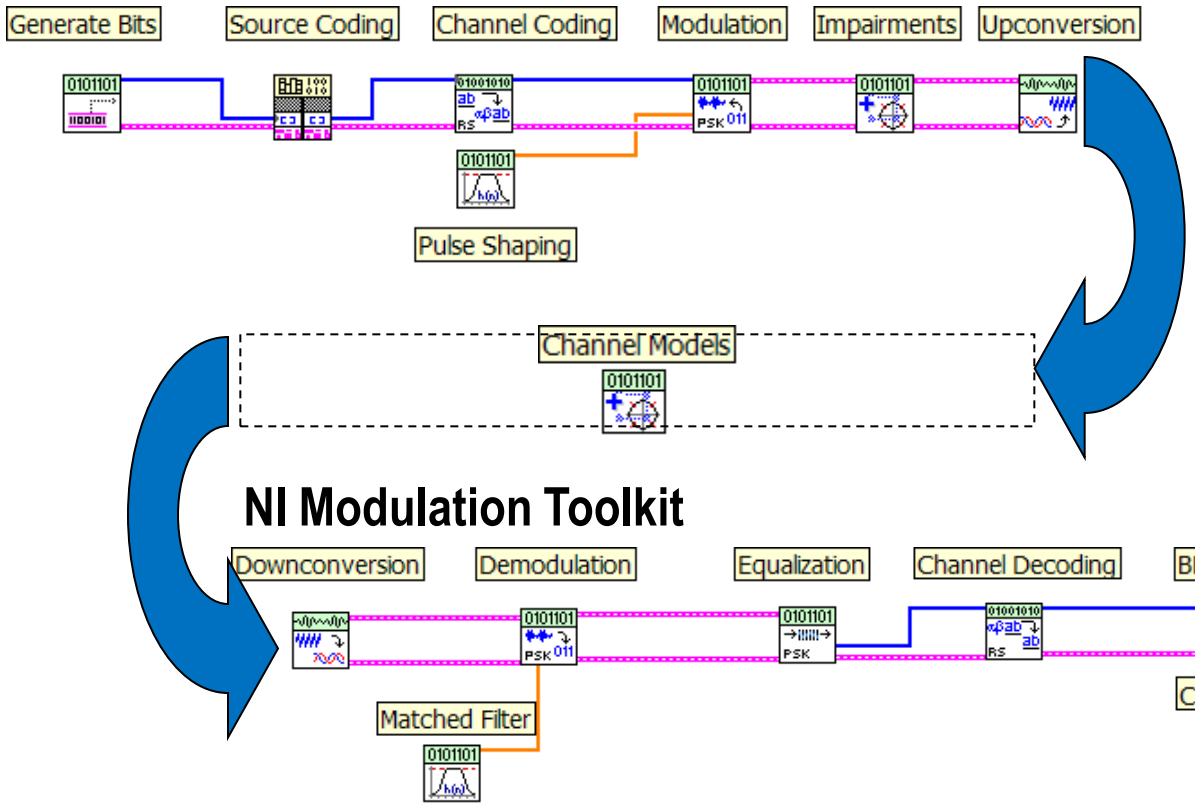
Digital Communication System





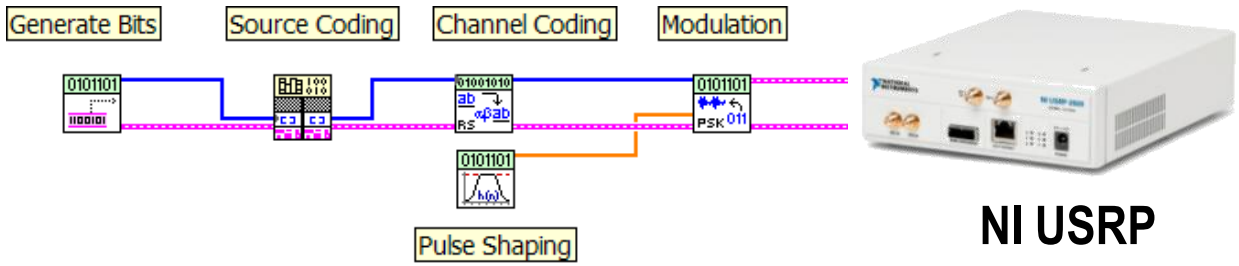
Digital Communication System

NI Modulation Toolkit



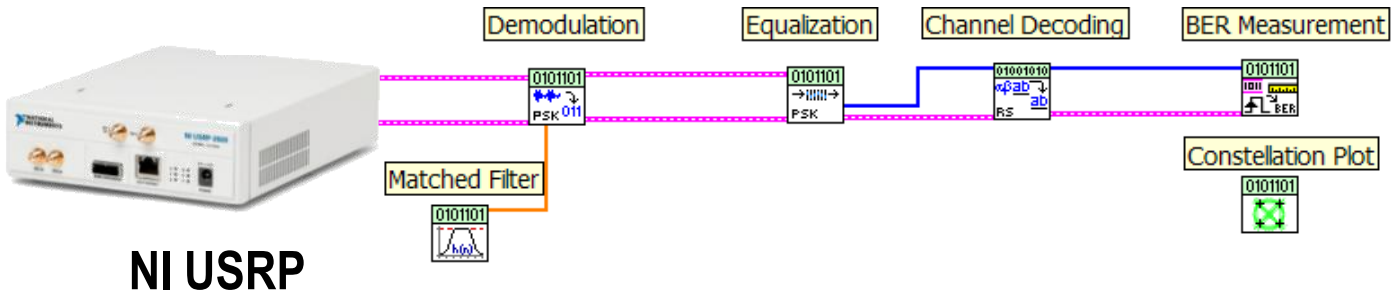
Digital Communication System

NI Modulation Toolkit



NI USRP

NI Modulation Toolkit

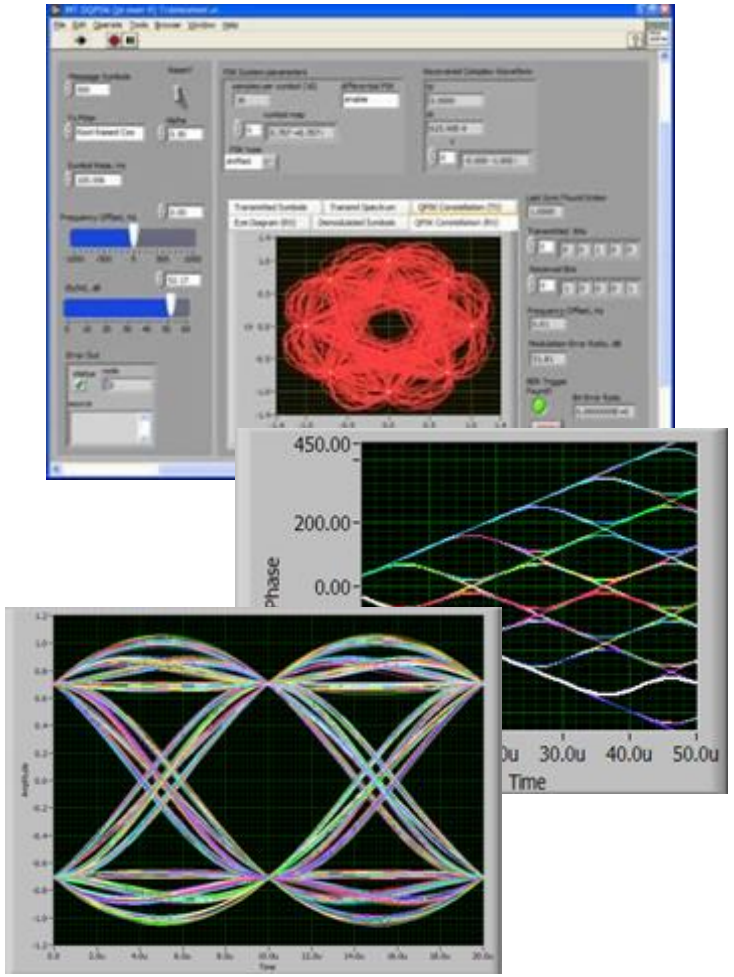


NI USRP

Communications System Design in LabVIEW

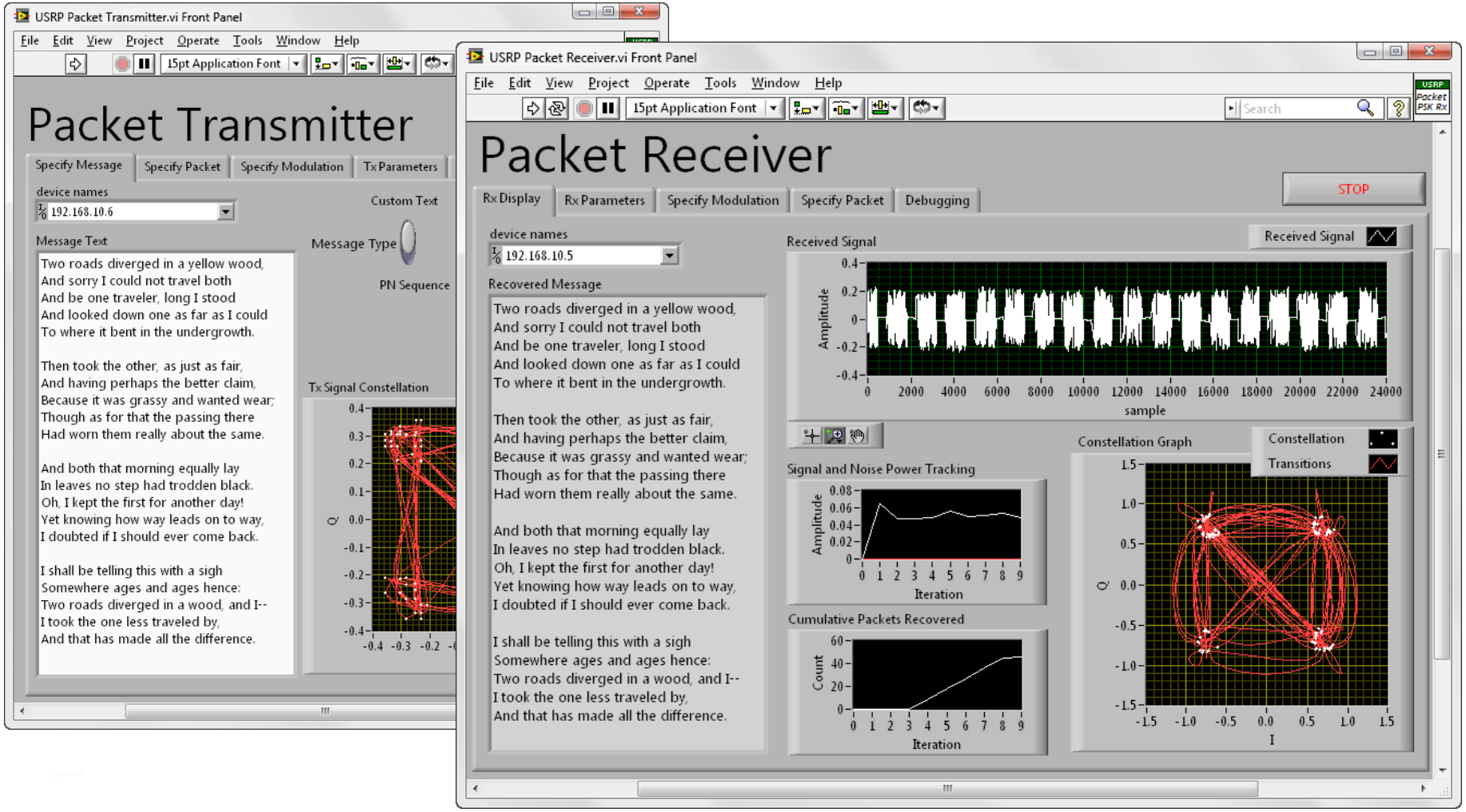
Modulation Toolkit

- Analog and Digital modulation formats
  - AM, FM, PM
  - ASK, FSK, MSK, GMSK, PAM, PSK, QAM
  - Custom
- Visualization
  - 2D and 3D Eye, Trellis, Constellation
- Modulation Analysis
  - BER, MER, EVM, burst timing, frequency deviation, ρ (rho)
- Impairments
  - Additive White Gaussian Noise (AWGN)
  - DC offset, Quadrature skew, IQ gain imbalance, phase noise
- Equalization, Channel Coding, Channel Models



Demo 4: QAM Tx / Rx Pair

Demo 5: Packet-based Transceiver



Demo 5: Packet-based Transceiver

NI USRP-2190
Transmitter

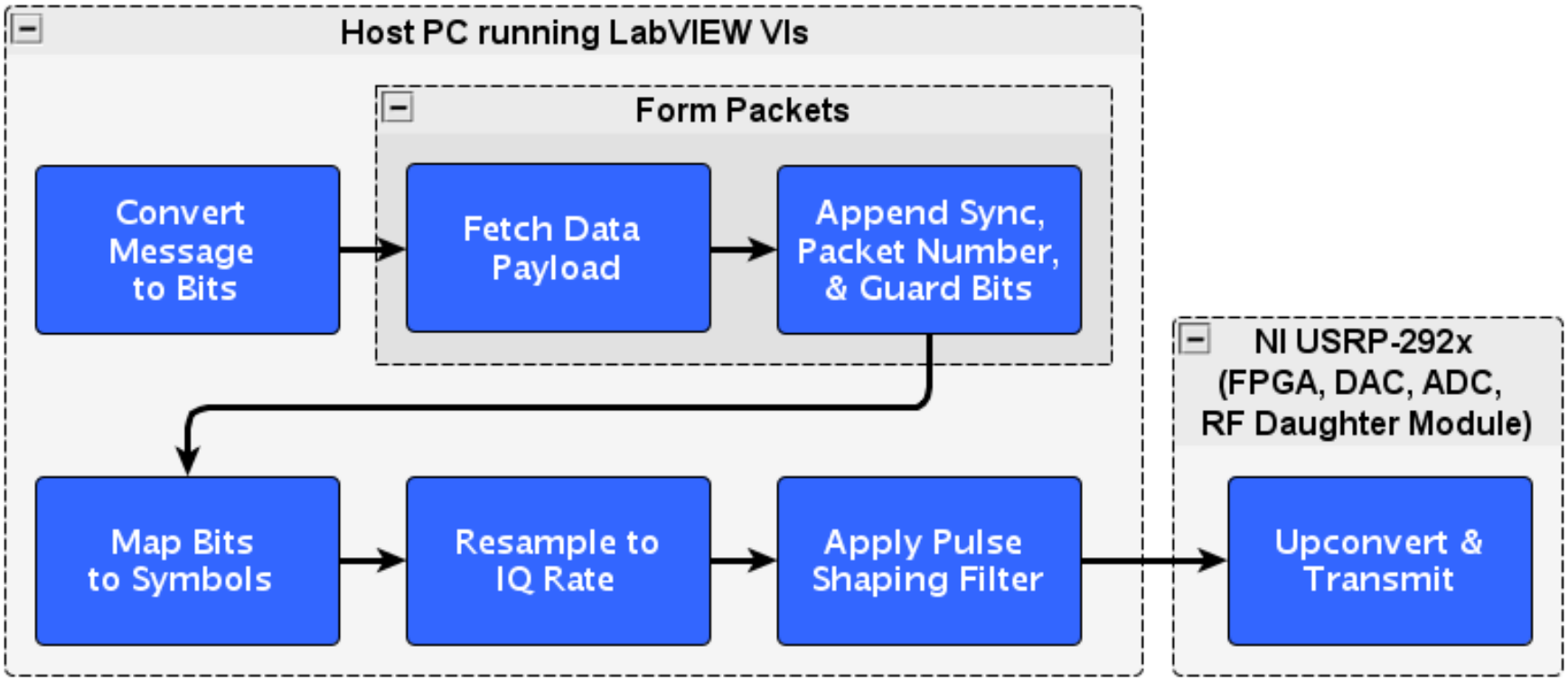
RF Signal
915MHz , PSK packets, 400kbps

NI USRP-2190
Receiver

NATIONAL INSTRUMENTS LabVIEW

- USRP control (Tx & Rx)
- Modulate Tx signal
- Demodulate Rx signal
- Reconstruct message

Transmitter Block Diagram



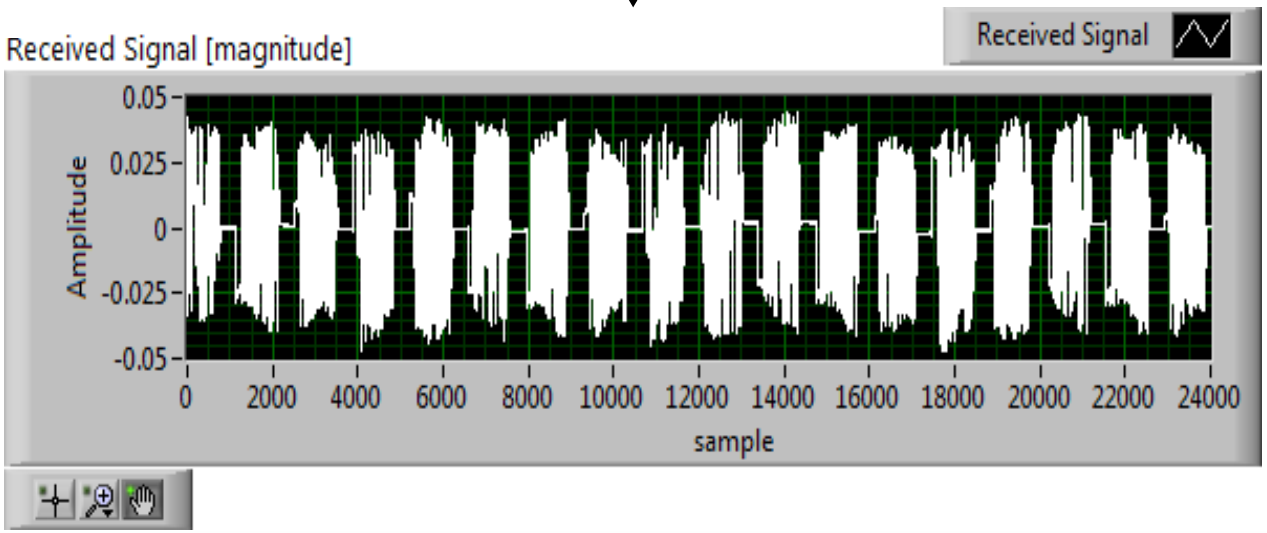
Packet Structure

Field	Length [bits]	Description
Guard Band	30	Allow initialization of Rx PLL, filters, etc
Sync Sequence	20	Frame and Symbol Synchronization
Packet Number	8	Range: 0-255 Used for reordering of packets and detection of missing packets
Data	64 - 256	Variable length data field. Length detected dynamically at Rx end
Pad	20	Allows for filter edge effects.

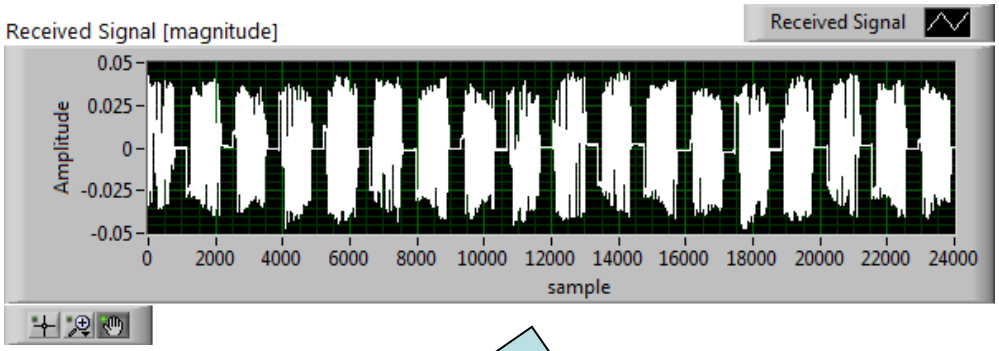
The Received Signal

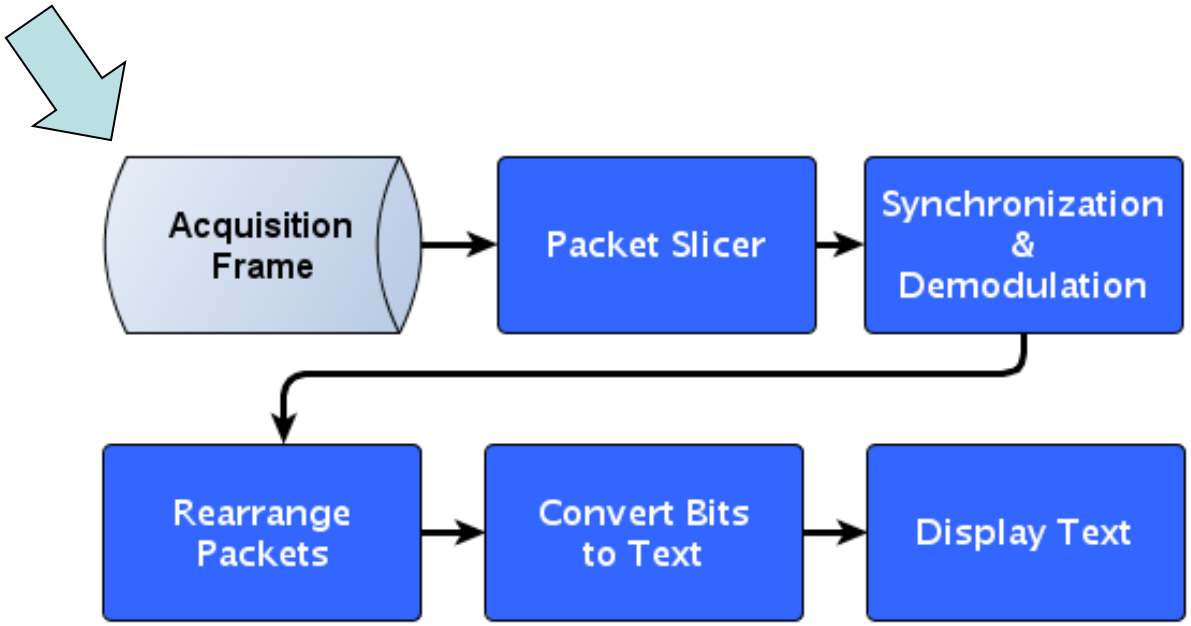
NI USRP-292x
(FPGA, DAC, ADC,
RF Daughter Module)

Receive and
Downconvert



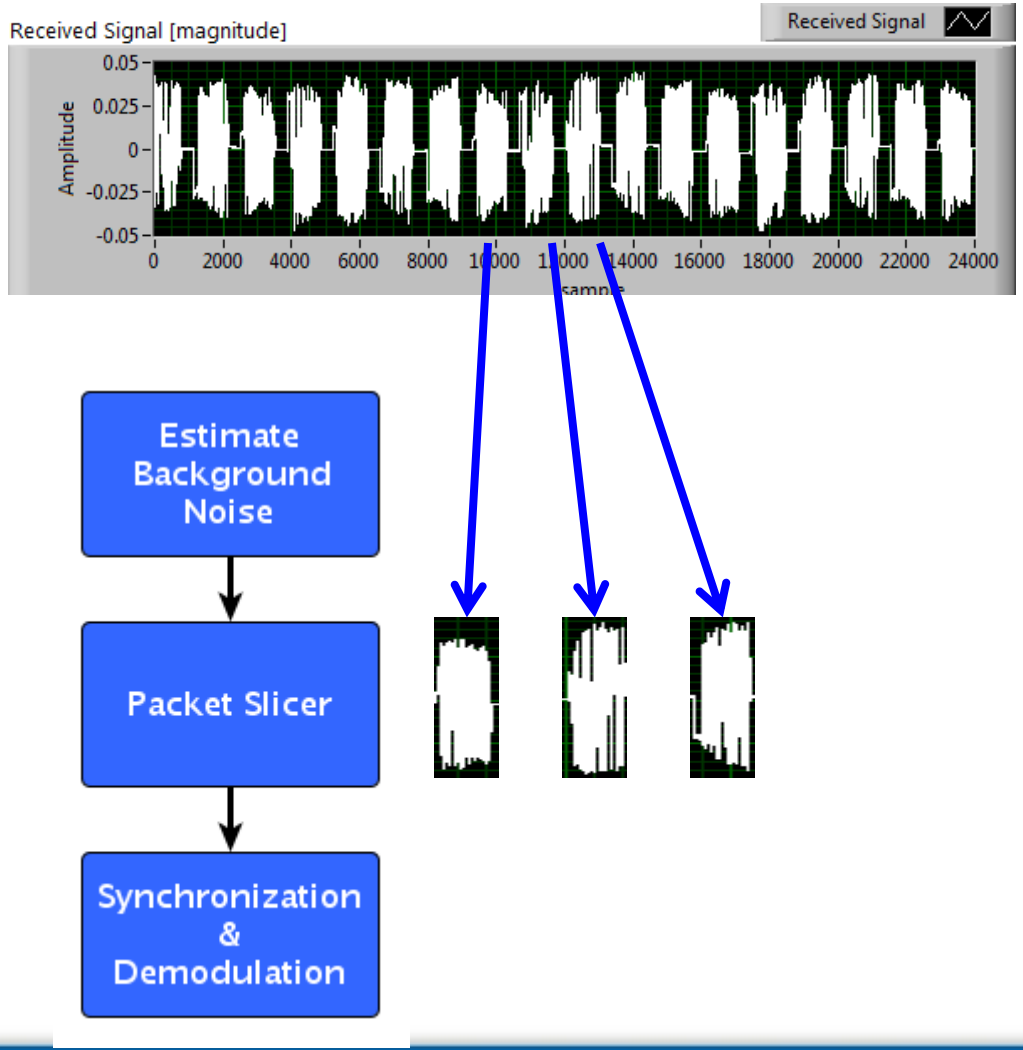
Receiver Block Diagram





Channel Activity Detection

- **Problem:** Inefficient to keep demodulator active for the entire acquisition frame—it needs to be applied only to packets
- **Solution:** Apply a channel activity detector to locate packet boundaries for a packet slicer



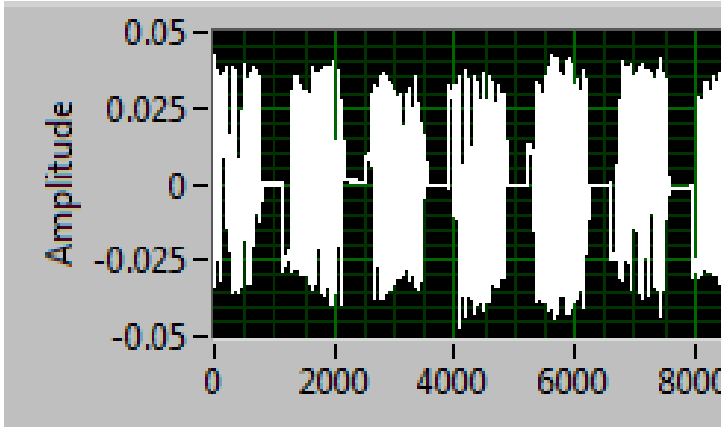
Error Tolerance

Problem: Errors at SNR >> 1

- Partial packets captured at frame edges
- Improper synchronization

Solution: Repetition Coding

- Repeat each packet **n** times
- Repeat entire message **m** times



Error Tolerance

- At SNR >> 1, errors introduced due to
  - Partial packet captured at frame edge interval
  - Improper synchronization
- Solution: Packet Repetition Coding
  - Repeat each packet n times (n=2 to 5)
  - Repeat whole message m times (m = 10)
- Proposed Schemes
  - CRC Check with two way ACKs
  - Reconstruct packets split across frames

Ideas for Extension

- Improved Error Tolerance
  - CRC check, convolutional coding, interleaving, etc…
- Bi-directional link with ACK messages
- OFDM
- Channel Equalization to improve range
- SW-based Rx gain control to ensure full use of available dynamic range
- Monitor / replicate common links
  - Bluetooth mouse
  - Key fob
- Additional message choices
  - Images, video, etc.

Next Steps

- Learn more about LabVIEW and NI-USRP
  - www.ni.com/usrp
- Find NI-USRP examples & participate in the NI-USRP online community
  - decibel.ni.com/content/groups/ni-usrp-example-labview-vis