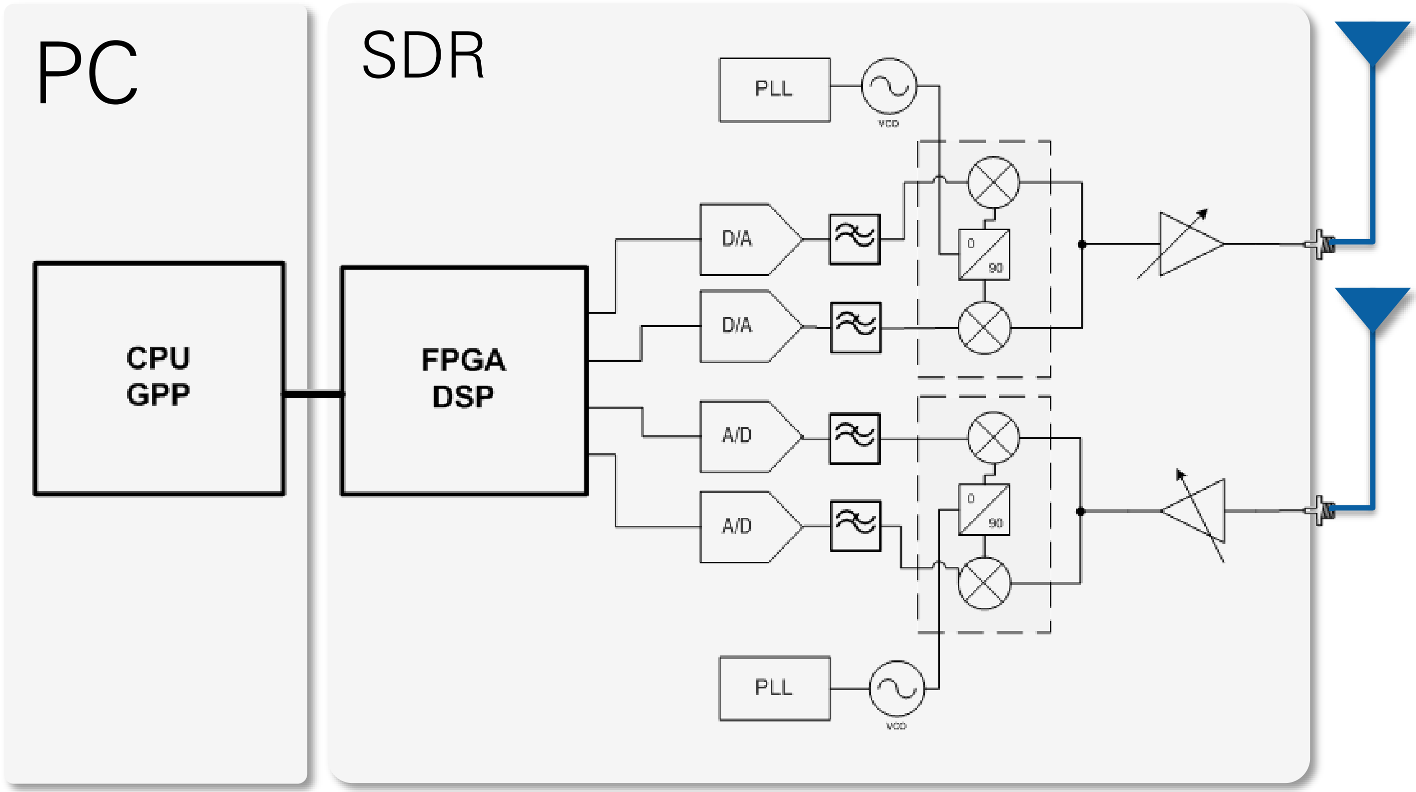
Prototyping Next Generation 5G Wireless Systems with Software Defined Radio

NATIONAL INSTRUMENTS

What is a Software Defined Radio?

Software Defined Radio (SDR) refers to the technology wherein software modules running on a generic hardware platform are used to implement radio functions…



Satellite Communication: ISEE-3 Rebooted After 36 Years

Launch: Aug 12, 1978
Contact: May 29, 2014

Space explorer changes course

Probe could be ret

WASHINGTON (UPI) — The American space probe that flew through the tail of a comet last September changed course and should swing back into orbit around Earth 28 years from now for possible retrieval by 21st century astronauts.

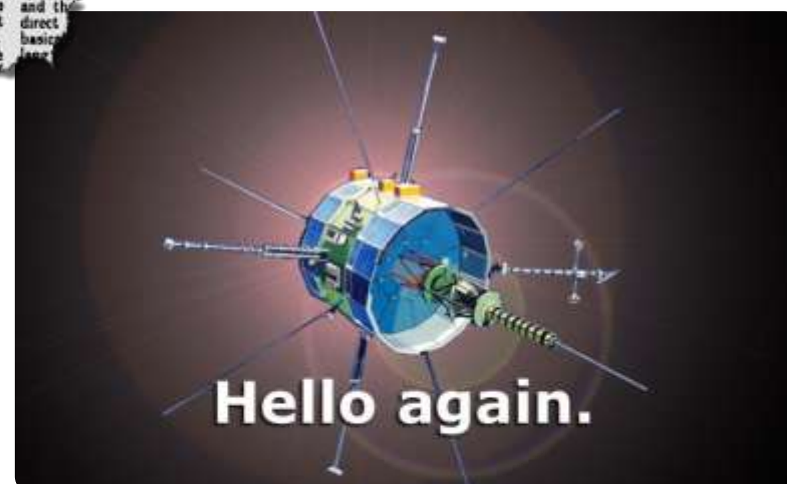
A series of rocket firings Monday put the half-ton International Cometary Explorer on a path in its orbit around the sun that should send it whipping around the moon on Aug. 10, 2014.

"We are now targeted for the moon, but it's a long time away," said flight director Robert Farquhar at the Goddard Space Flight Center, Greenbelt, Md. "I'm not going to be able to wait around."

The spacecraft was maneuvered out of its original Earth orbit by swinging around the sun, and the return close encounter with the moon is expected to place the craft back into an elongated Earth orbit.

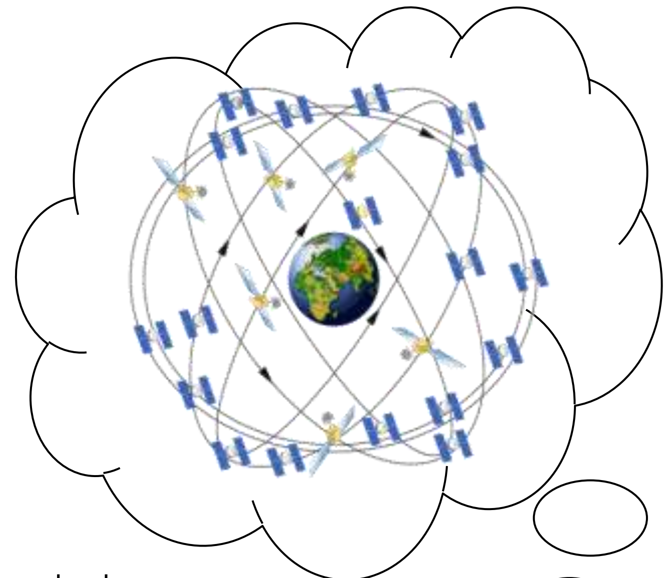
There, Farquhar said the probe

PUBLISHED
9 APRIL 1986



Source: spacecollege.org

GPS Simulation

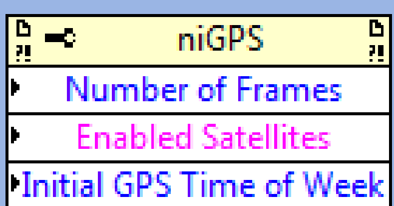


Things to Simulate

- Poor signal strength
- View of satellites obstructed
- Position constantly changing

GPS receiver behaves as
if it sees real satellites

GPS Toolkit Creates
Signal in LabVIEW



NI USRP-2920
Generates Signal

GPS Receiver

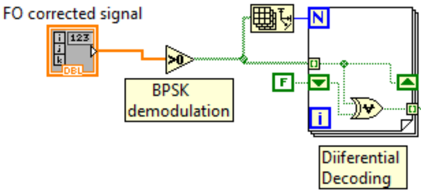
Precision Clock
(10 MHz OCXO)

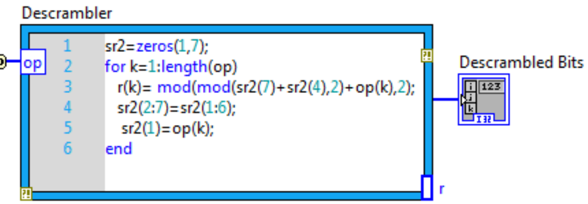
WiFi Physical Layer Prototyping

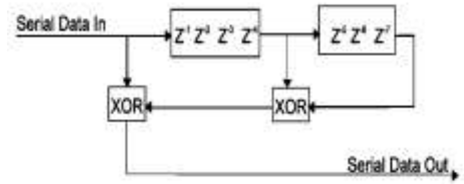
Dr. Murat Torlak

- Continuously monitoring multiple wifi channels
- Demodulation and descrambling of 802.11b beacon signals
- Identification of hotspots, tracking relative power levels

Demodulate	Descramble







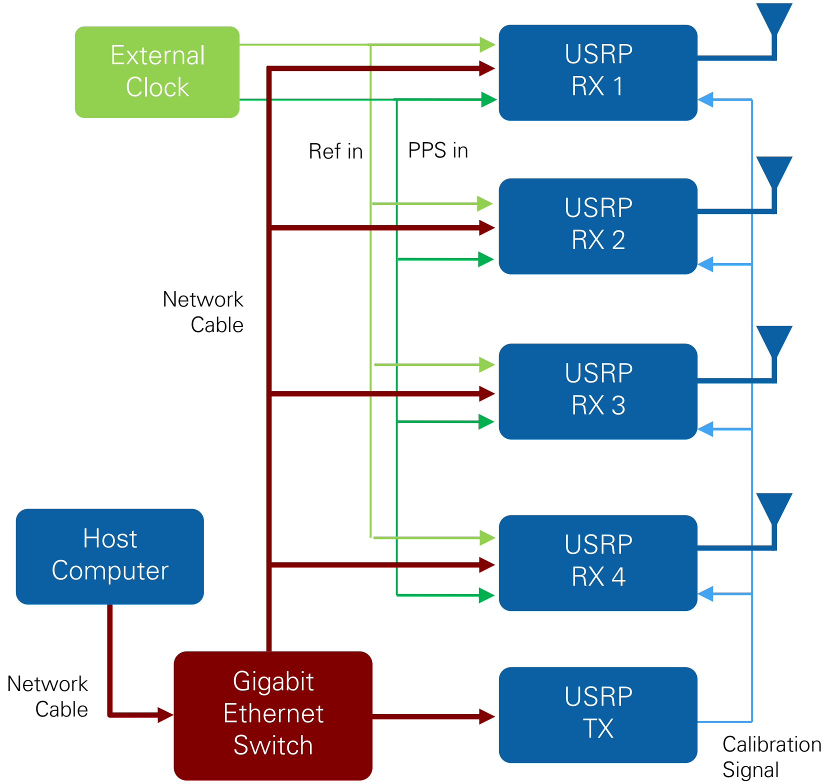
802.11b SSID Decoding

Carrier Detection → Frequency Offset Estimation & Correction → Demodulation & Descrambling → Interpret the frame for SSID

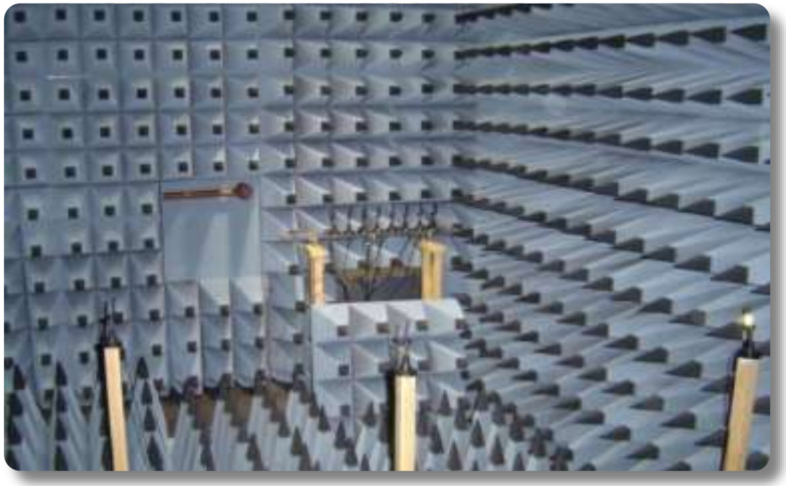
Position Detection & Localization

Imperial College London
Prof. Athanassios Manikas

- Testing MUSIC direction finding algorithm
- Rapid prototyping in LabVIEW with MathScript RT
- Synchronized up to12 USRP devices
- Reference provides continuous phase alignment compensation



Direction Finding (uniform linear array)



SDR Algorithm Prototyping Applications

Wireless Research – Some Perspective

Pope election 2005

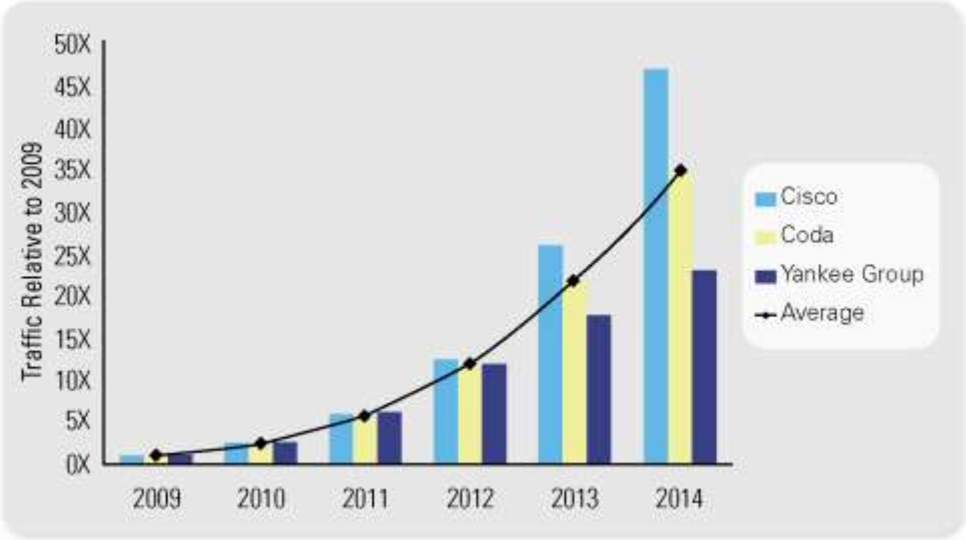
Pope election 2013

What a difference in just 8 years!

Wireless Bandwidth Explosion

Wireless Investments Escalating to address inevitable bandwidth crunch.

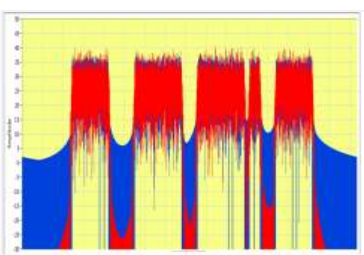
Industry Forecasts of Mobile Data Traffic



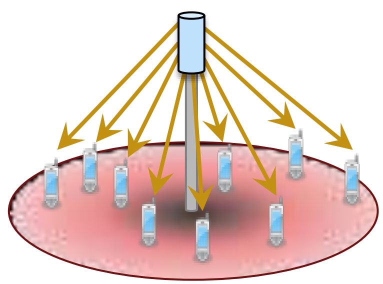
From Mobile Broadband: The Benefits of Additional Spectrum (FCC Report 10/2010)

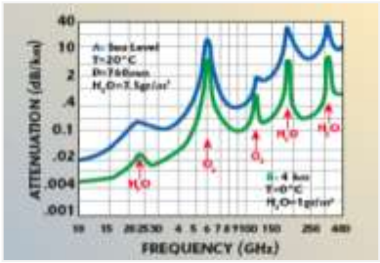
Candidate 5G Technologies In Need of Prototyping

New Modulation:	New MIMO Tech:	New Spectrum:	Higher Density:
PHY Waveforms	**Massive MIMO**	**mmWave**	**Densification**
Improve spectral efficiency over OFDM through signal structure improvements such as NOMA, GFDM, FBMC, & UFMC	Dramatically increased number of base station antenna elements to focus downlink transmissions increasing capacity, reducing interference and power.	Exploring extremely wide bandwidths at higher frequency ranges once thought impractical for commercial wireless.	Increased access point density across a geography for reduces power, improves spectrum reuse for increased data rates.

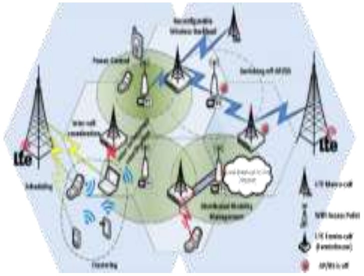


GFDM (red curve) vs. OFDM (blue curve)



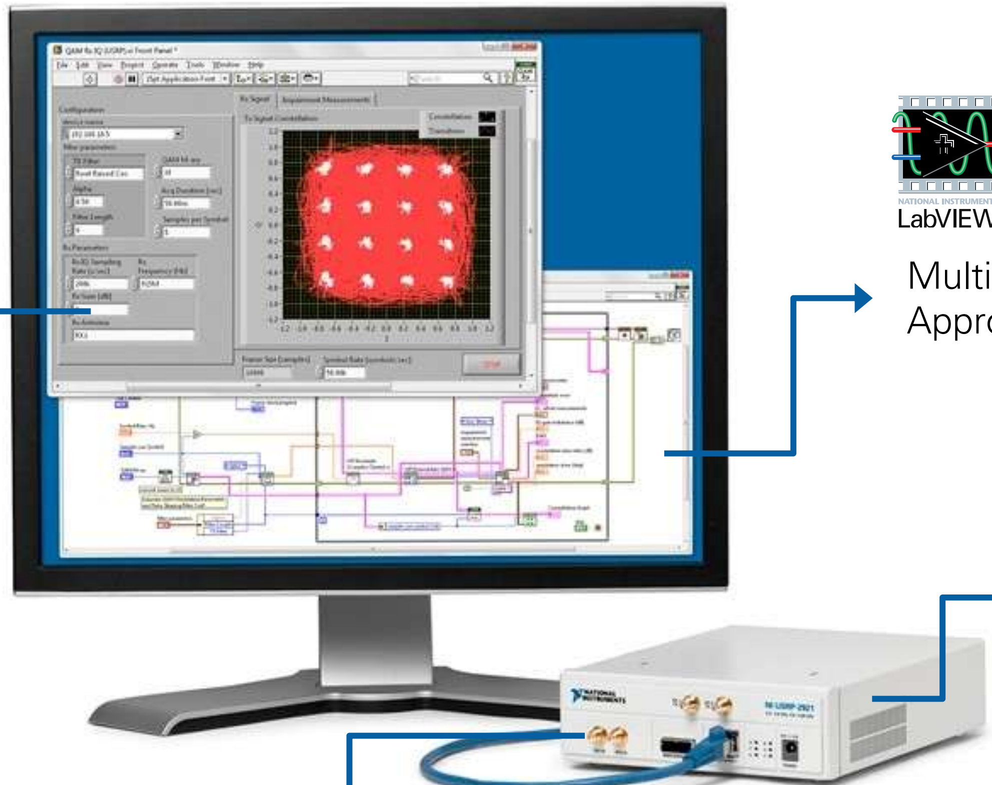


28 GHz, 38 GHz, 60 GHz, and 72 GHz



NI USRP
Software-Defined Radio Ecosystem

Extensive Analysis Libraries



Multiple Programming Approaches

GCC

NI Universal Software Radio Peripheral (USRP) Up to 6 GHz

High-performance FPGA-based Architecture

NI USRP RIO

Software Defined Radio

Applications

- 5G wireless prototyping
- High channel count MIMO
- Wide bandwidth, low latency

Audience

- Industry Research
- Mil/Aero/Gov

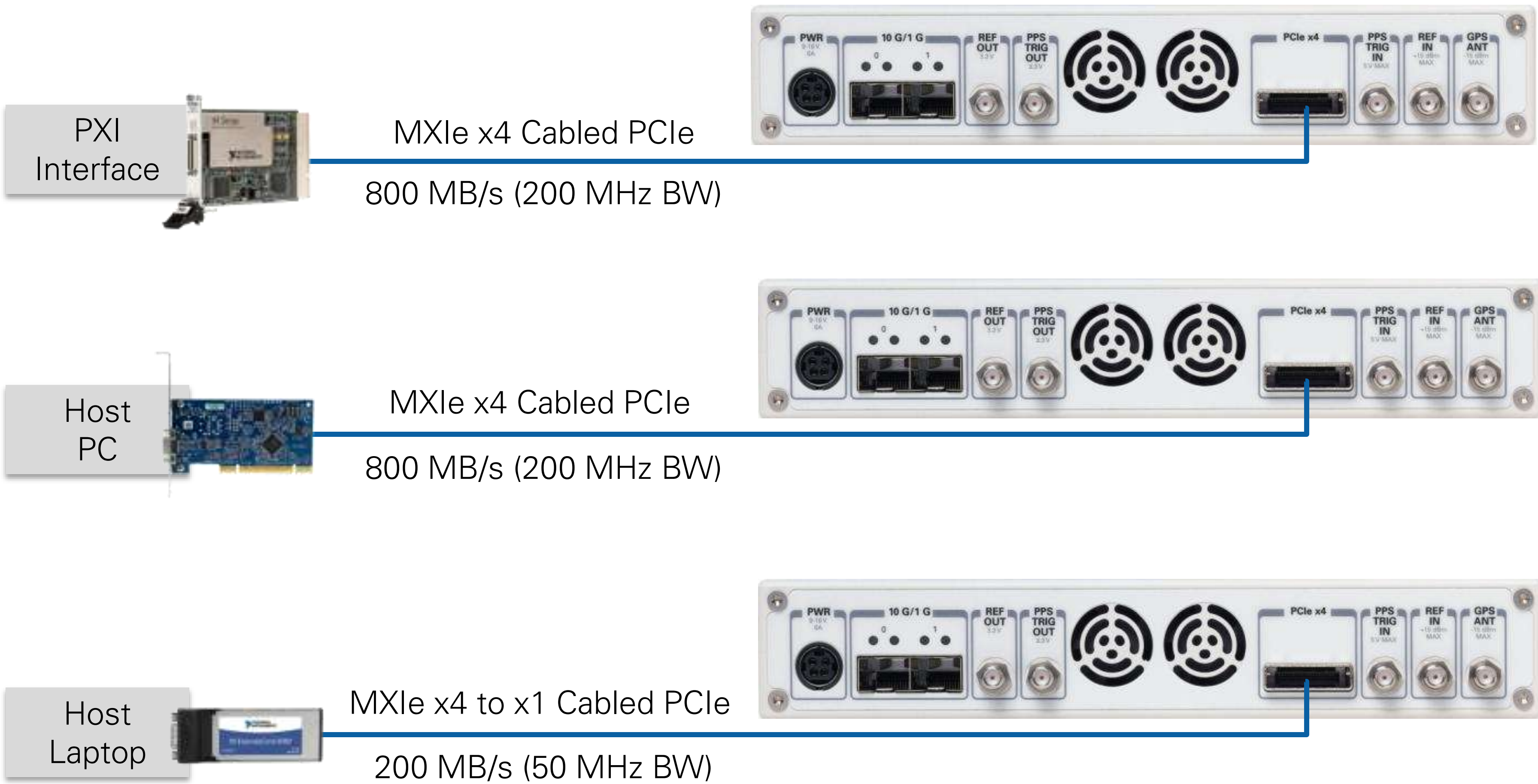
Front

Back

Features

- 2 Channel TX/RX with RF options 50 MHz – 6 GHz
- Customizable Xilinx Kintex 7 FPGA, K7410T
- Optimized RF Performance
  (400 point characterization)
- Powered by the LabVIEW RIO Architecture
- 40 MHz Real-time Bandwidth
- PCIe x4, 800 MB/s streaming
- GPS Disciplined Clock option

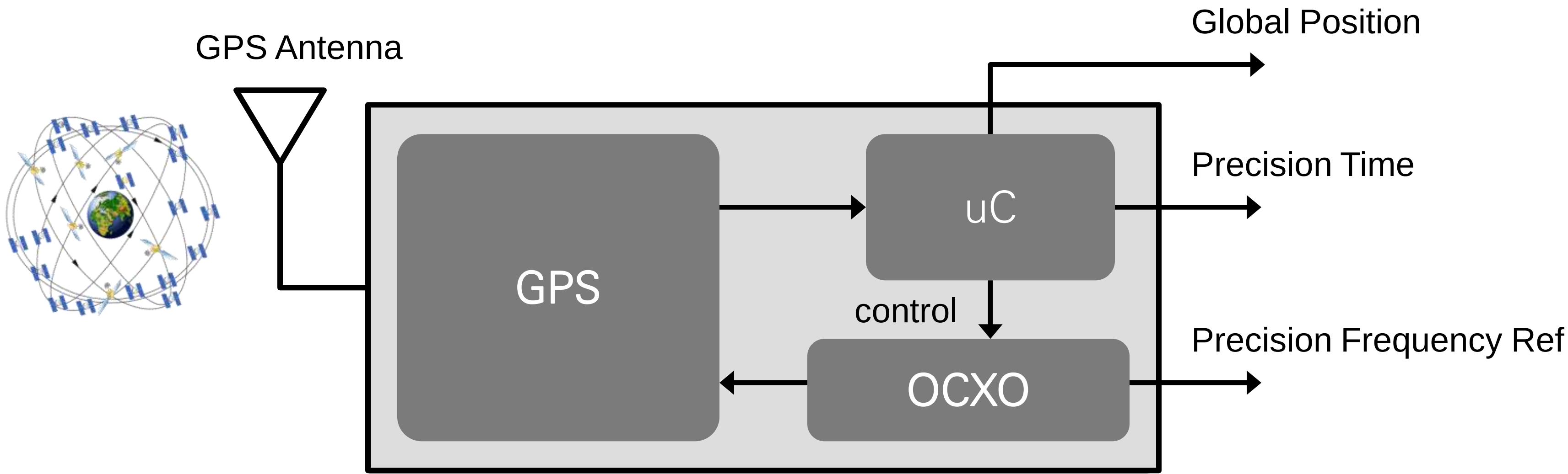
NI USRP RIO MXIe Interface Options



* Max possible data rate (Theoretical real-time bandwidth)

NI USRP RIO

Integrated GPS-Disciplined Clock



NI USRP-295xR Devices

- Improved frequency accuracy
  (with or without GPS lock)
- Global time & frequency sync
- GPS location information

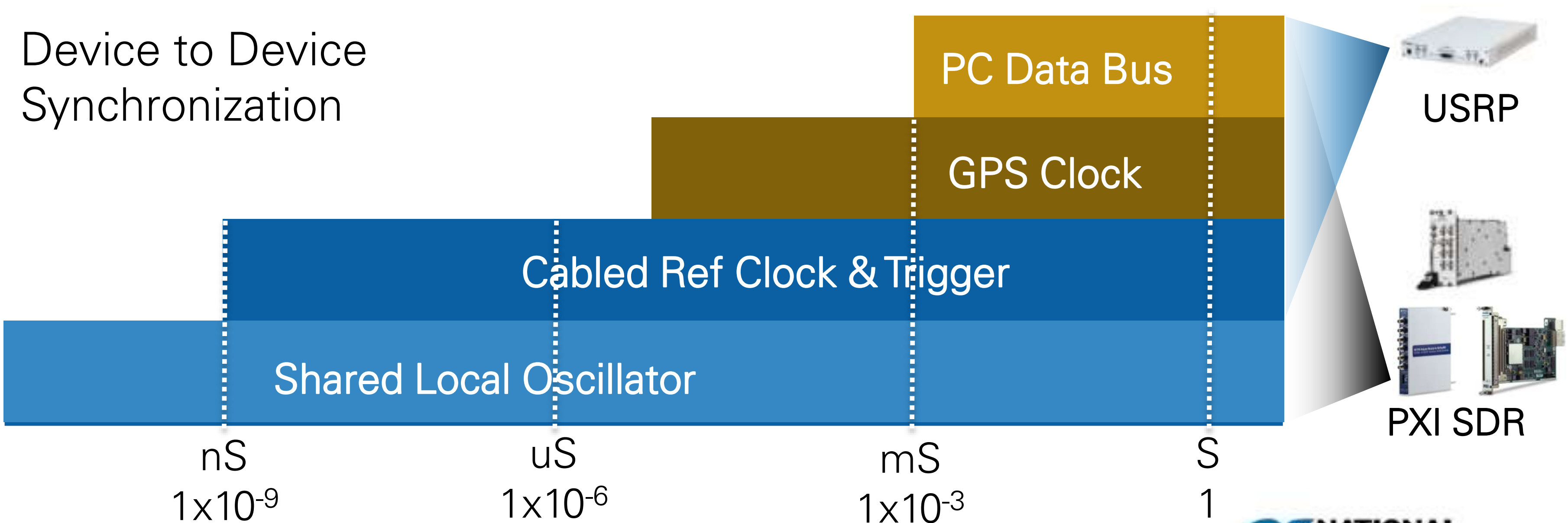
NI USRP RIO

Synchronization

Frequency Accuracy

NI USRP RIO	GPS-Disciplined	Frequency Accuracy	
		Stand-alone	GPS Lock
NI USRP-294x	No	± 2.5 ppm	-
NI USRP-295x	Yes	± 25 ppb	± 0.5 ppb

Device to Device Synchronization

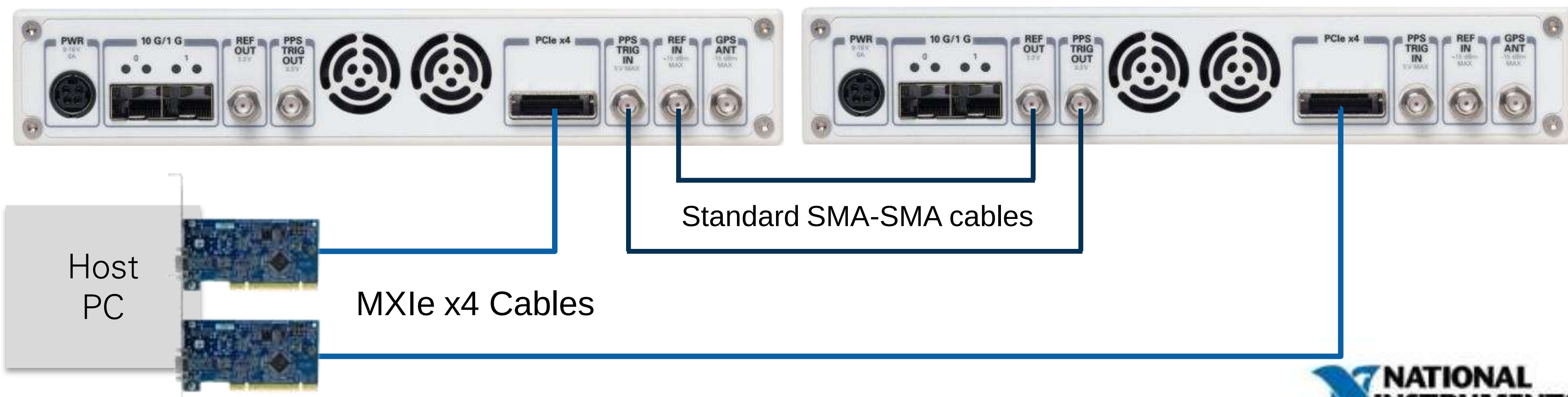


Building High Channel Count Systems

- Mount 2 units in a compact 1U rack
- Sync time and freq with daisy chain of 10 MHz and PPS

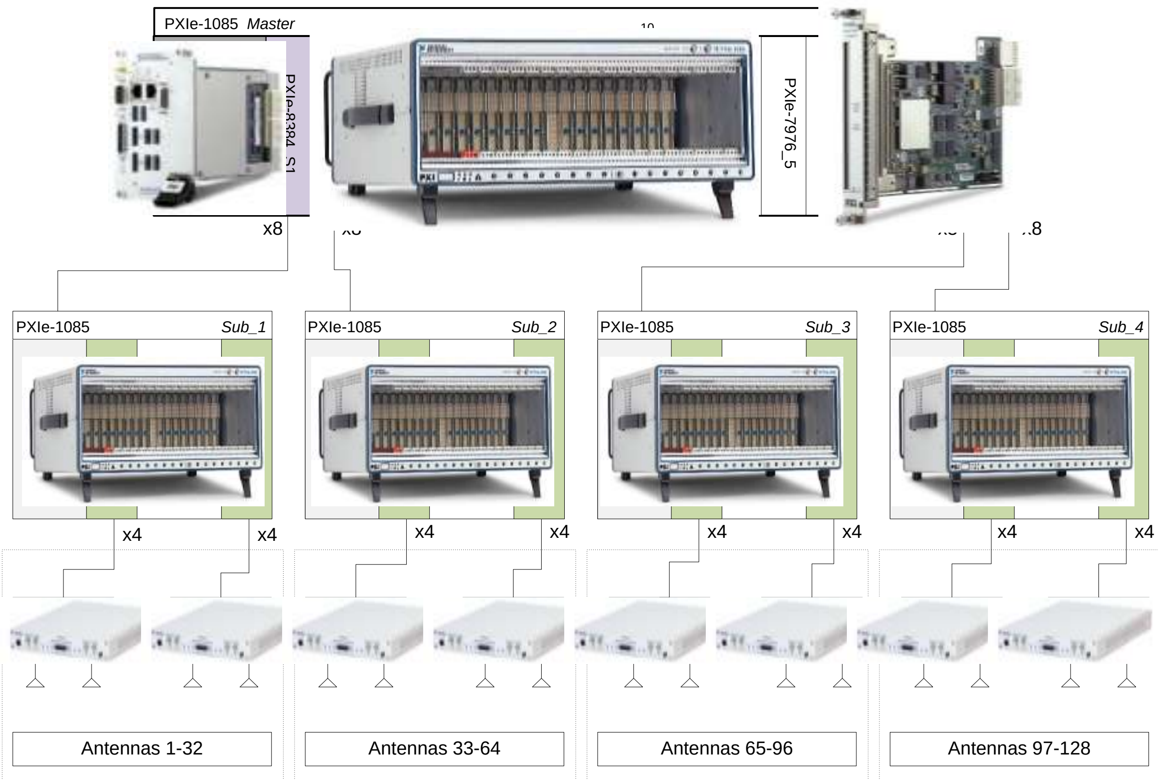
Front: USRP RIO – 4x4 MIMO

Back: USRP RIO – 4x4 MIMO



5G Massive MIMO Application Framework

Goal: Build a cellular massive MIMO,100x10 antenna system to validate theoretical results with real time processing

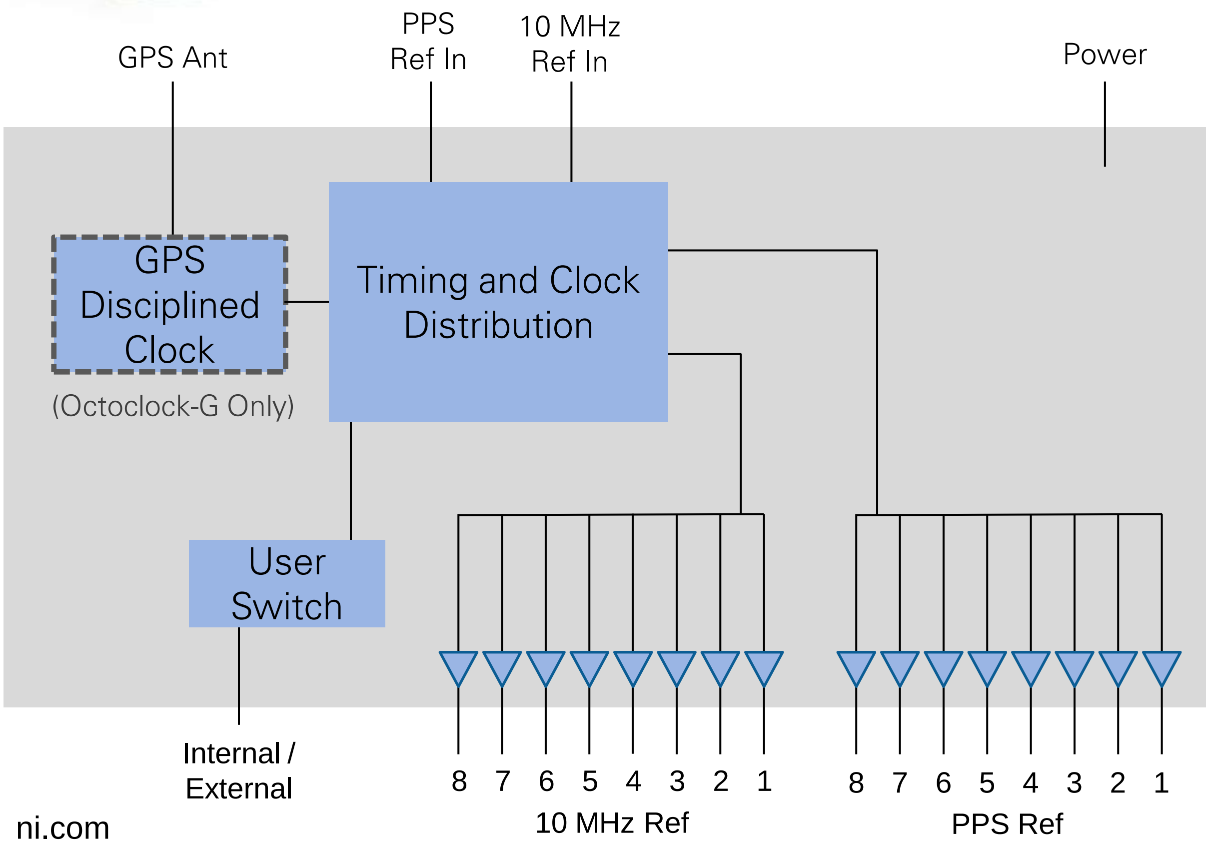


LTE-like System Parameters

Parameter	Values
No. of base station antennas	64 - 128
RF Center Frequency	1.2 GHz – 6 GHz
Bandwidth per Channel)	20 MHz
Sampling Rate	30.72 MS/s
FFT Size	2048
No. of used subcarriers	1200
Slot time	0.5 ms
Users sharing time/freq slot	10

- MIMO base station communicating with a single channel mobile user
- IQ sampling of 15.7GB/s on the uplink and downlink
- TDD operation enabling channel reciprocity

OctoClock – 8 Channel Clock Synchronization



Applications

- Time and frequency synchronization for large channel count systems

Features

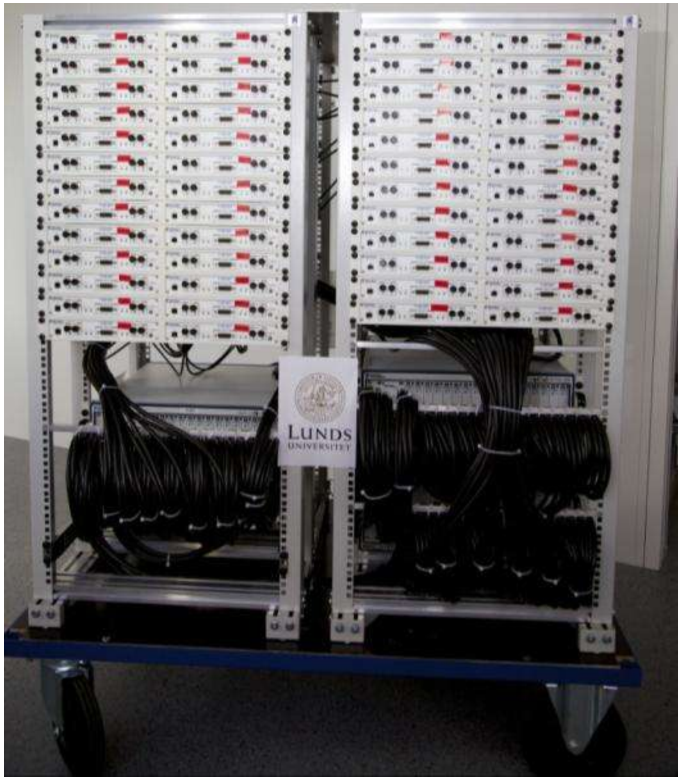
- 8 Channel 10 MHz and PPS Distribution
- Choose between Internal / External sources
- Optional integrated GPS disciplined clock

5G Massive MIMO at Lund University, Sweden

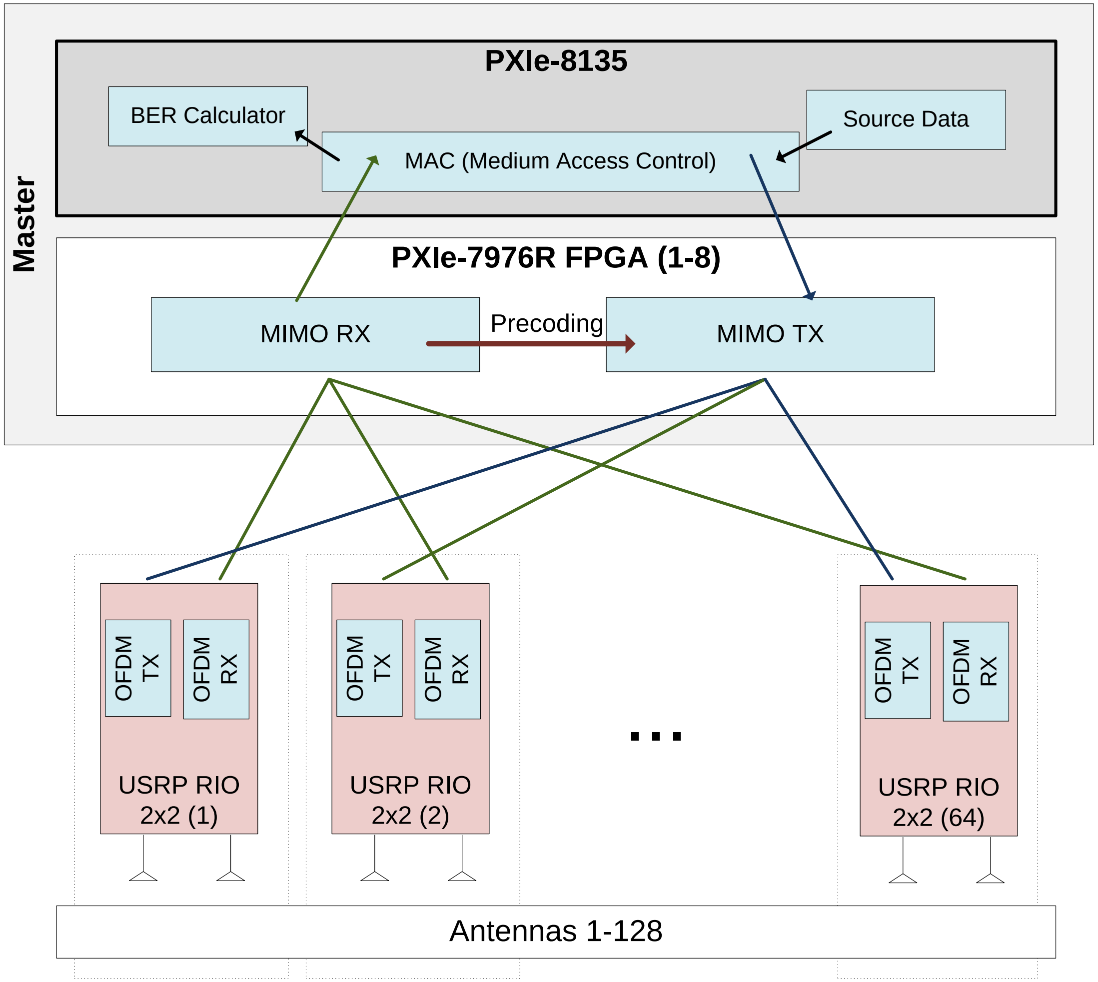
Goal: Build a massive MIMO,100x10 antenna system to validate theoretical results with real time processing

Prof Ove Edfos

Prof Fredrik Tufvesson

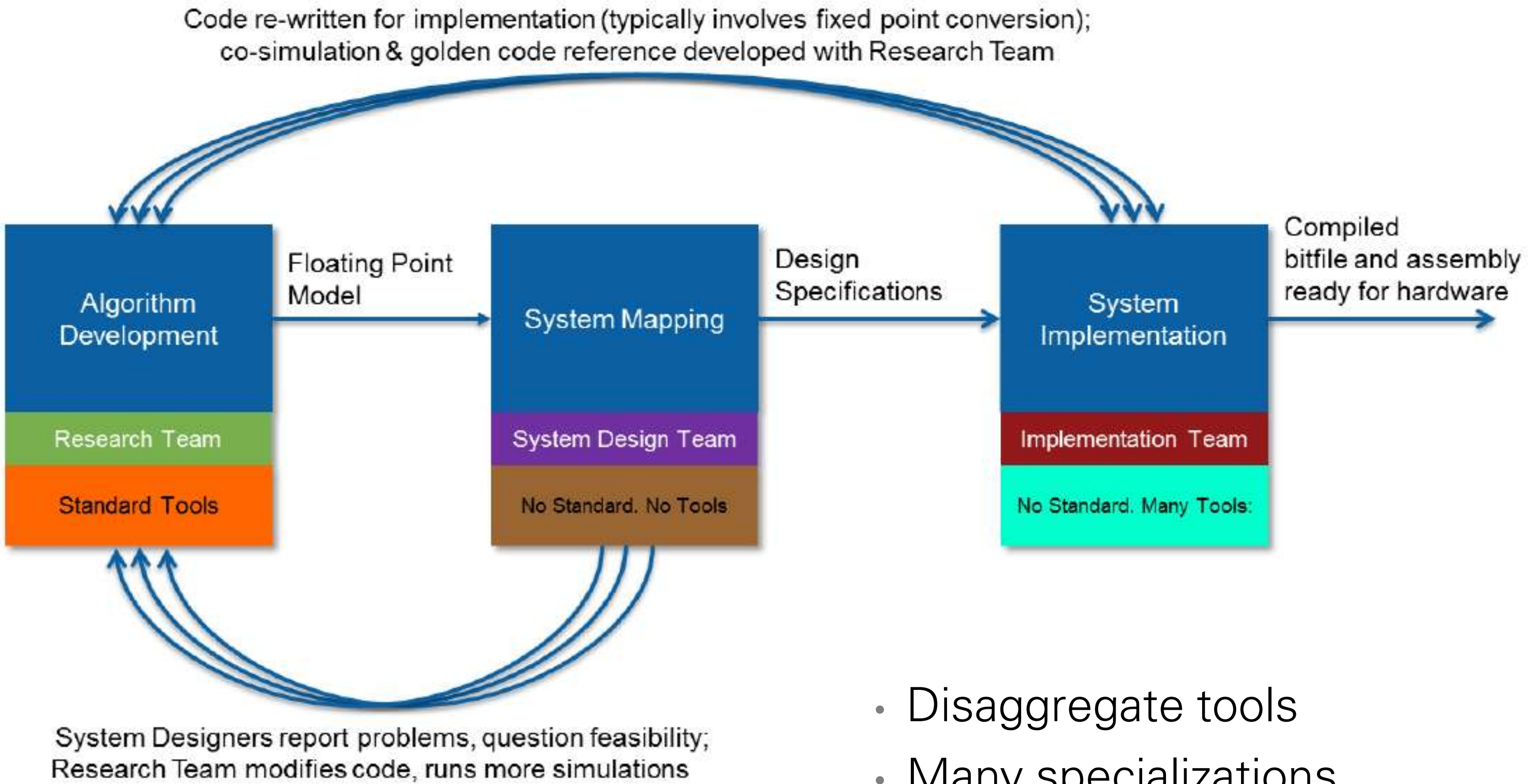


Massive MIMO – Algorithms & Software



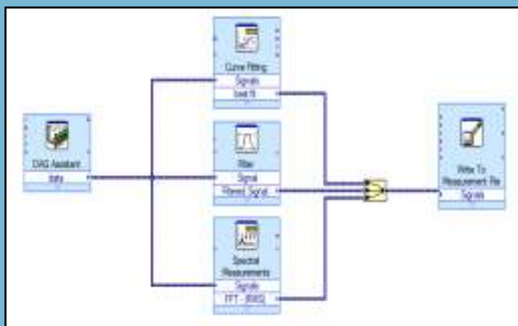
- OFDM PHY processing at each radio head
- Sub-channels streamed to /from FlexRIO for MIMO
- Precoding applied with low latency P2P connection
- MAC processing on the host controller

Classic Tool Flow

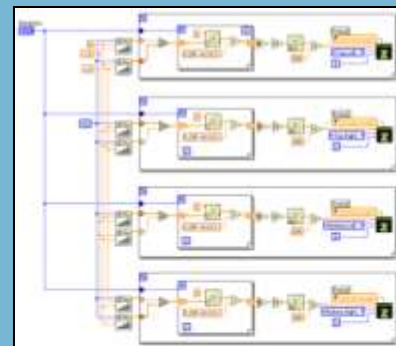


- Disaggregate tools
- Many specializations
- Longer design cycles
- Increased time to result

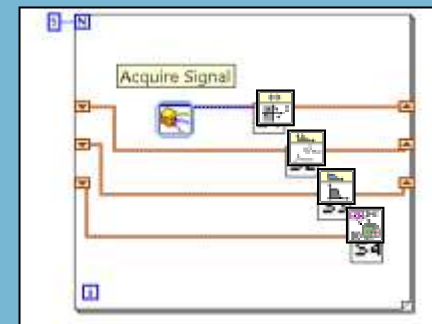
Integrated Tool Flow with LabVIEW



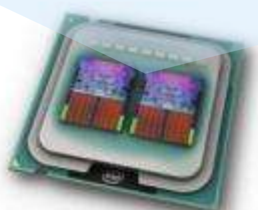
Task Parallelism



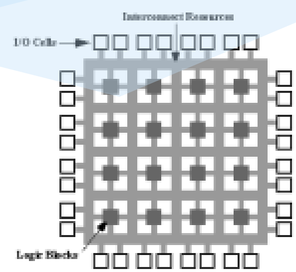
Data Parallelism



Pipelining



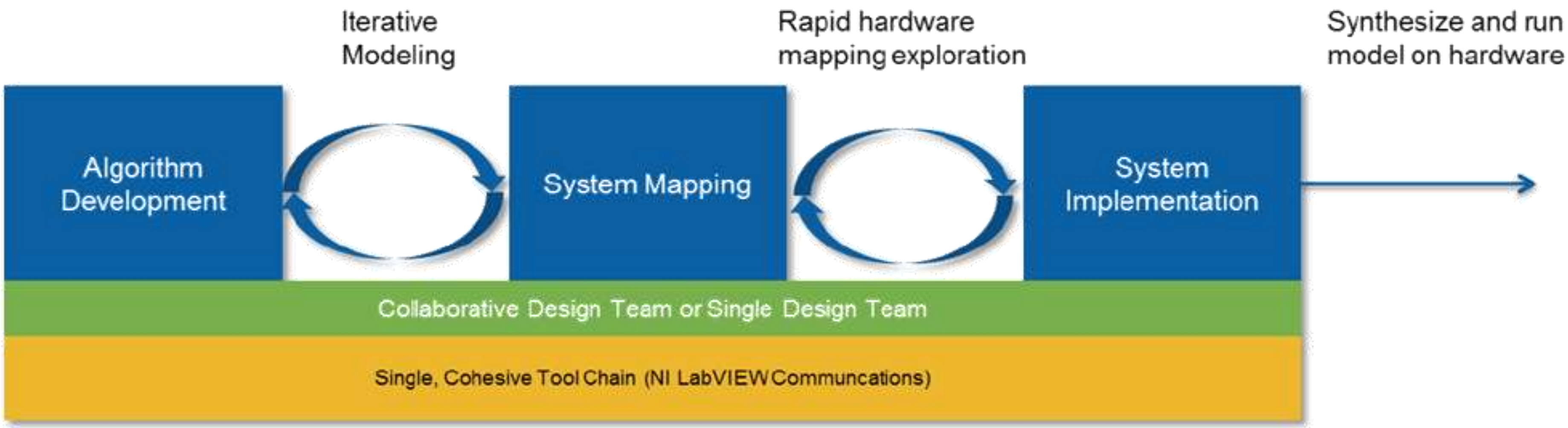
Multicore Processors



FPGAs

NATIONAL INSTRUMENTS

Commitment to Streamlining the Design Flow



Investing in accelerating productivity with LabVIEW:

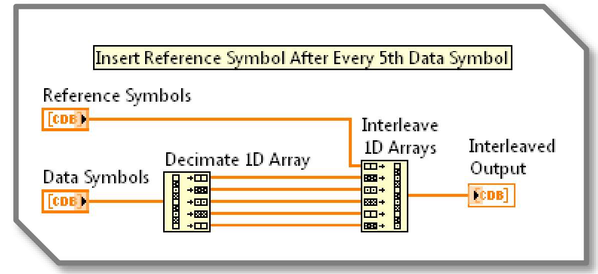
- Mapping algorithms across processors
- Context aware float-to-fixed conversion
- Integration of custom IP such as .m, C, HDL
- Code sharing across traditional hardware boundaries

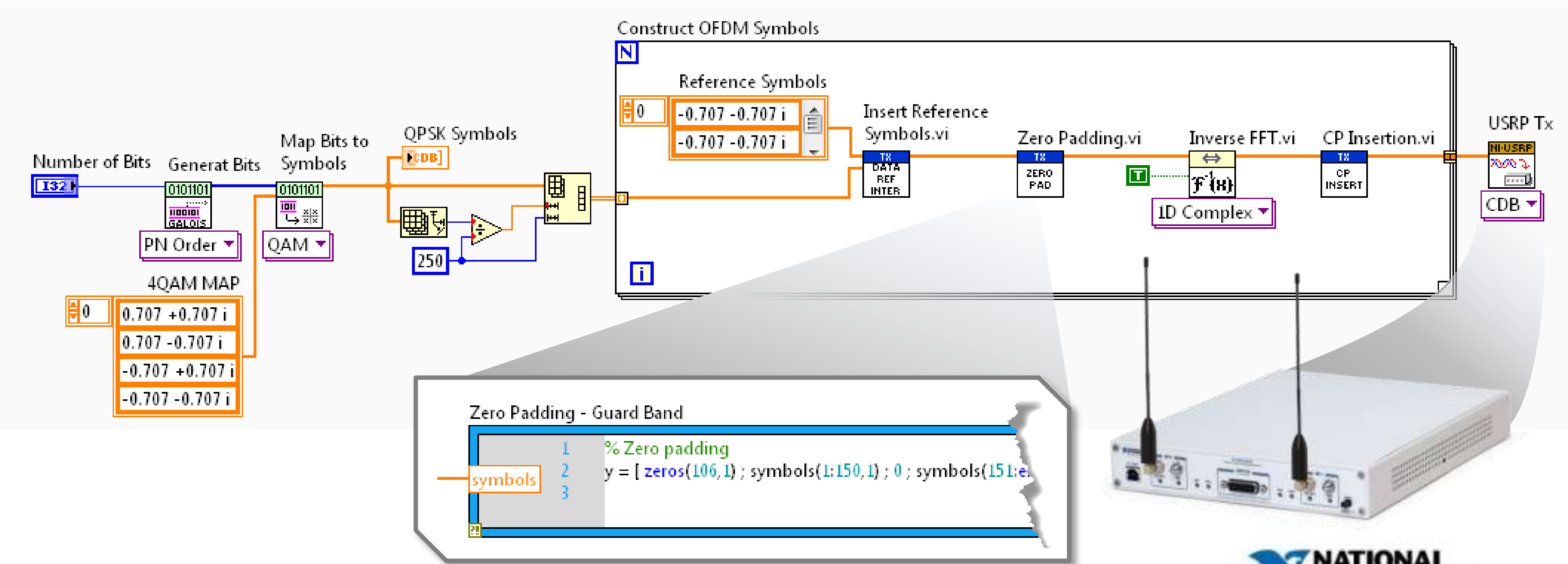
Faster time to prototype "rapid prototyping"

Common Development Environment for Host & FPGA

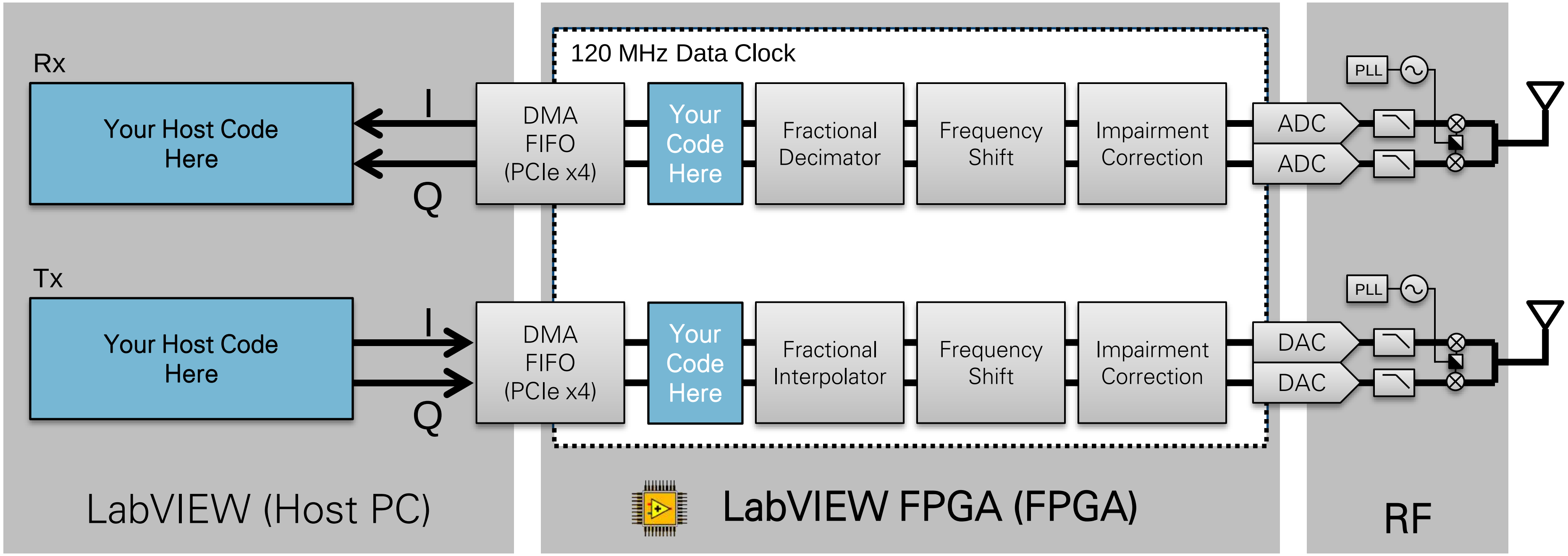
Example: Host Based OFDM Transmitter

- Describe the algorithm graphically
- Combine models of computation
- Seamlessly integrate I/O





NI USRP RIO Driver Software (Host + FPGA)



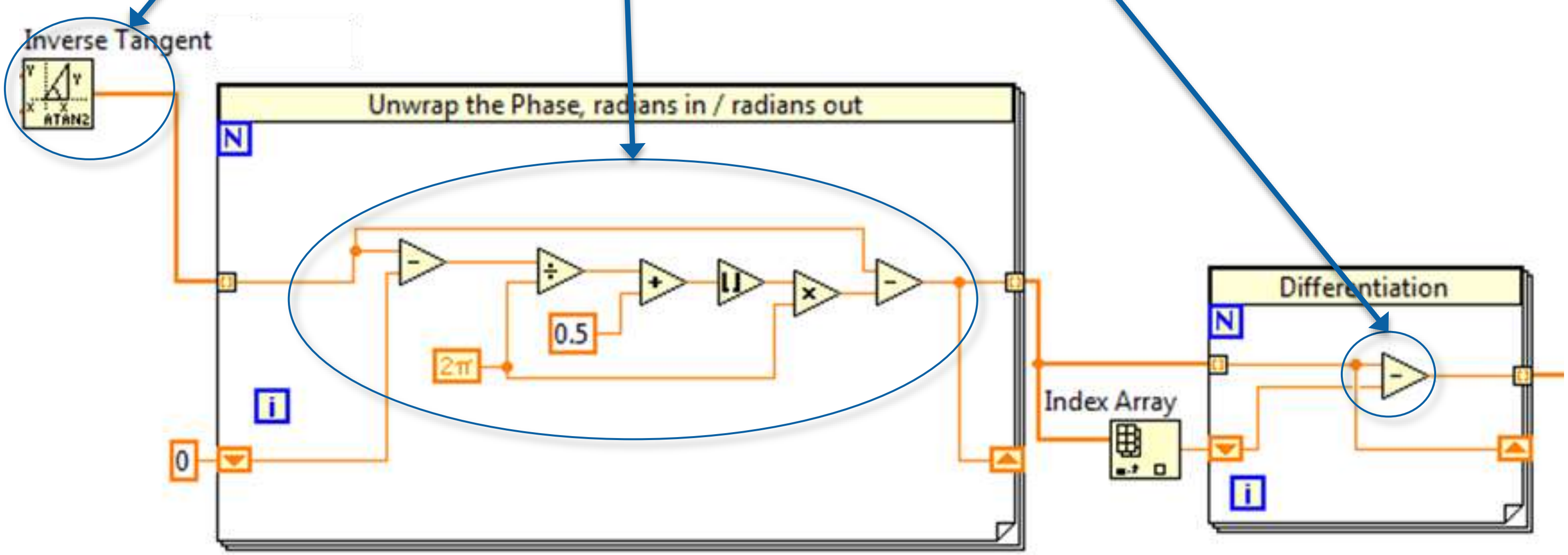
PC or Laptop

Cabled PCIe

USRP RIO

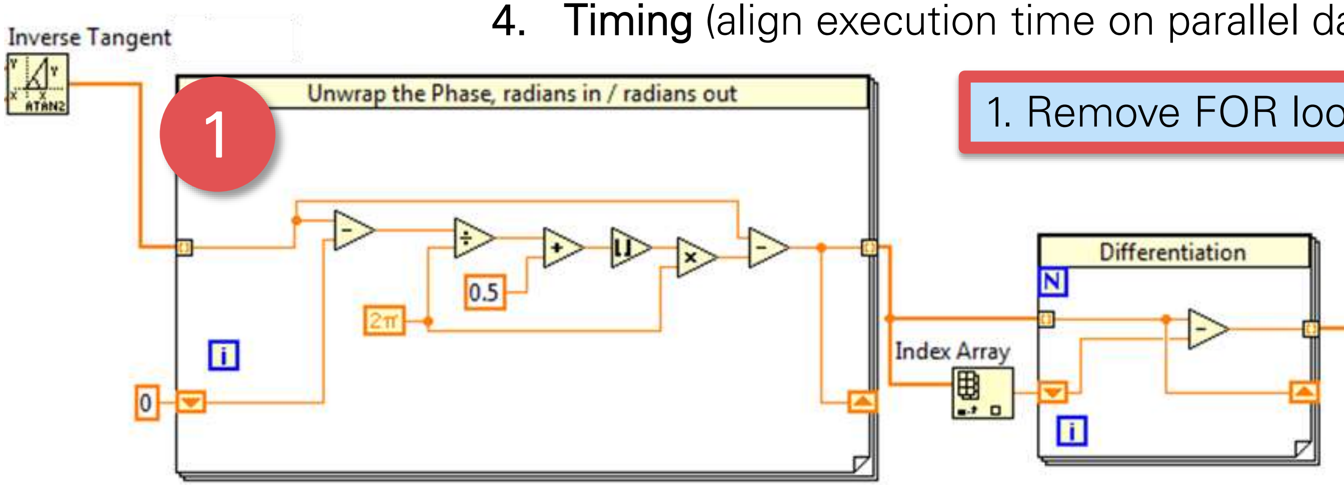
Demodulating Broadcast FM Radio

Baseband IQ → Calculate phase → Unwrap phase → Differentiate phase → Demodulated FM



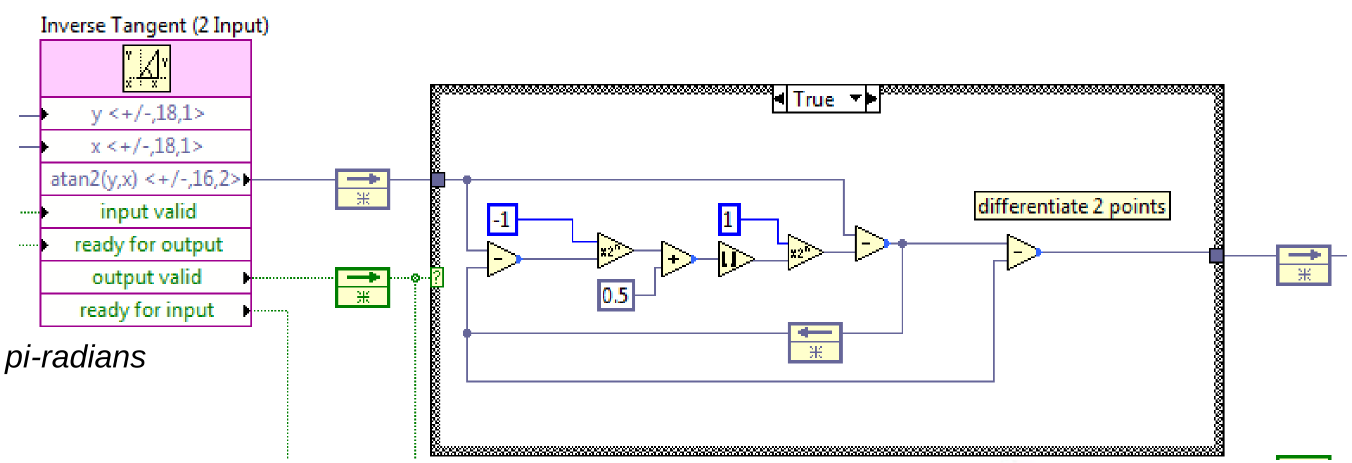
Algorithm to FPGA Implementation

1. **Frame Based to Single Point Processing**
2. **Resource Limited** (memory and functions like divide)
3. **Floating to Fixed Point** (limited precision, i.e. pi)
4. **Timing** (align execution time on parallel data paths)



1. Remove FOR loop

FPGA



**Note: FPGA Inverse Tangent uses pi-radians removing pi from Unwrap equation*

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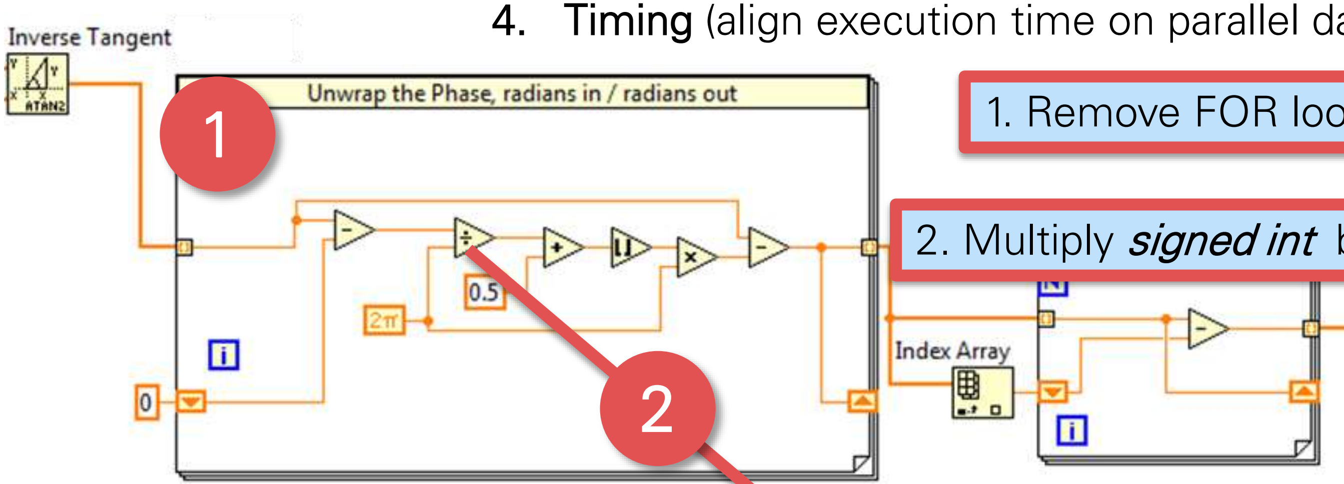
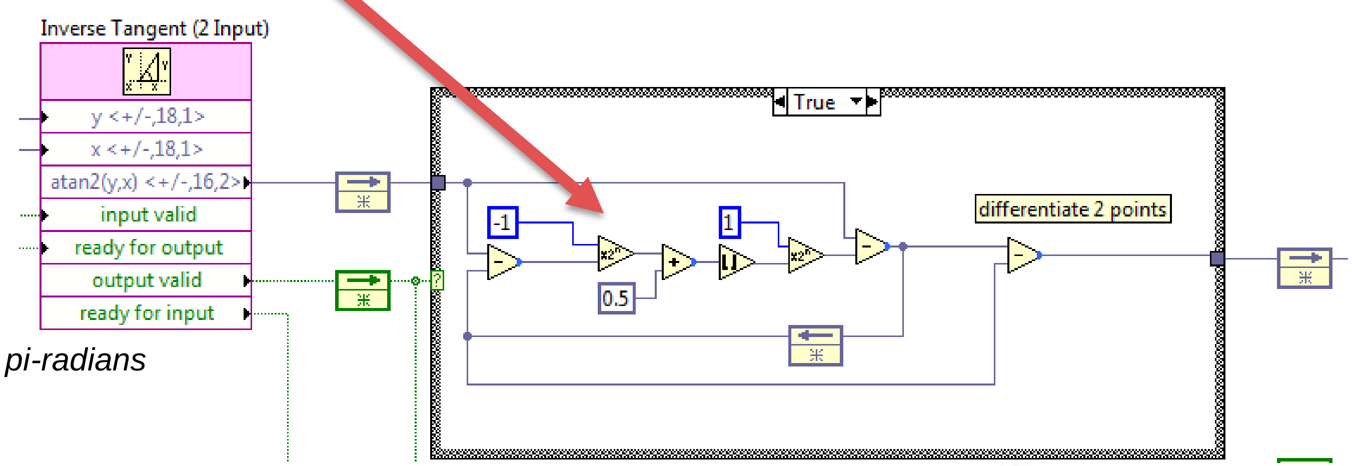


1. Remove FOR loop

2. Multiply ***signed int*** by 2^{-1} rather than divide

FPGA



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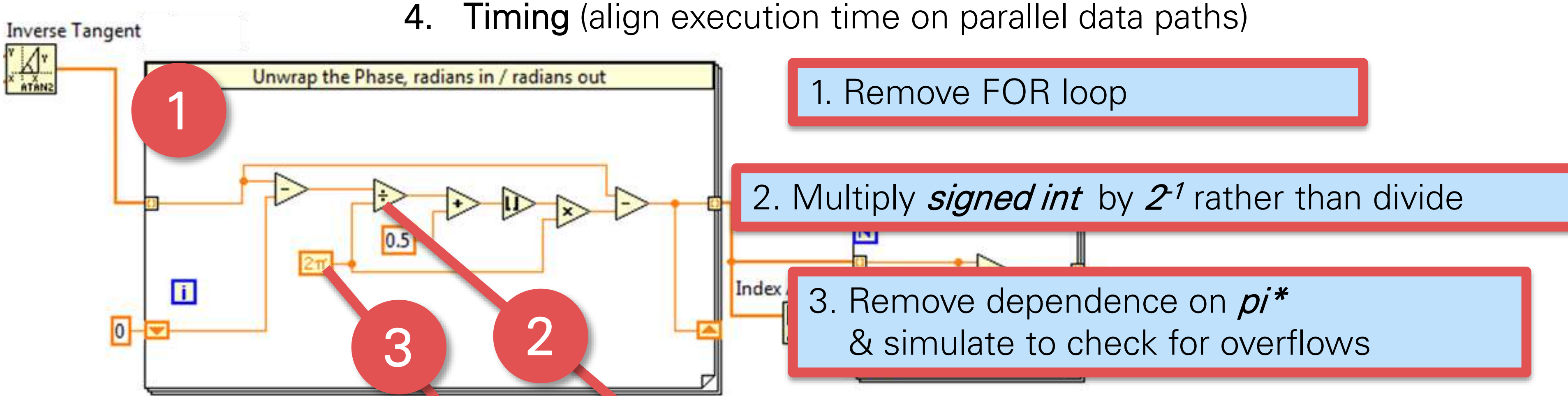

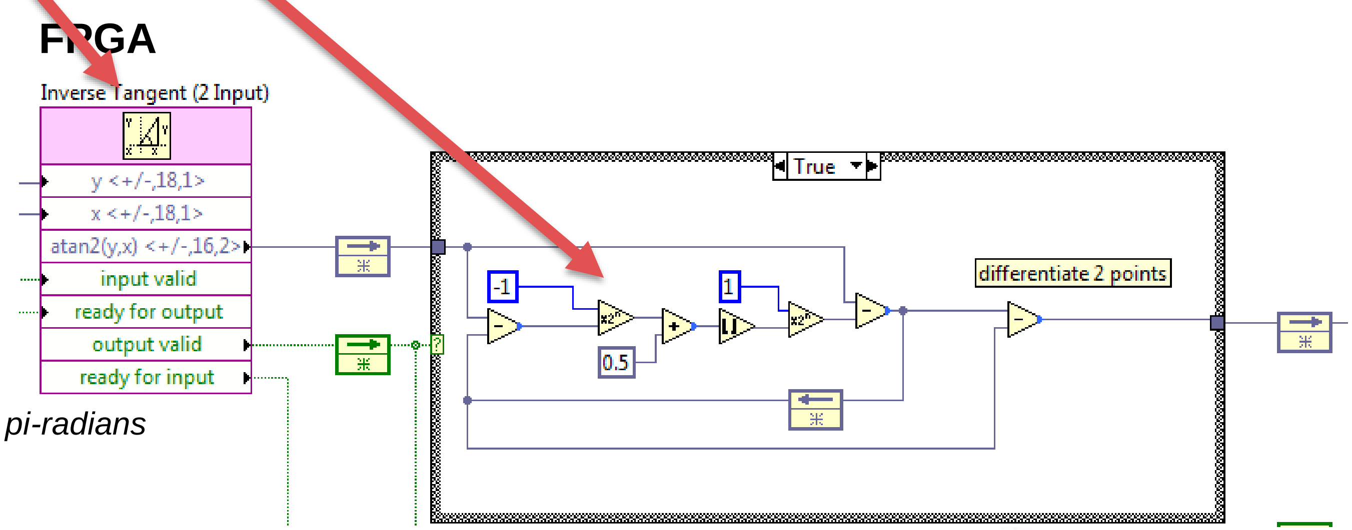

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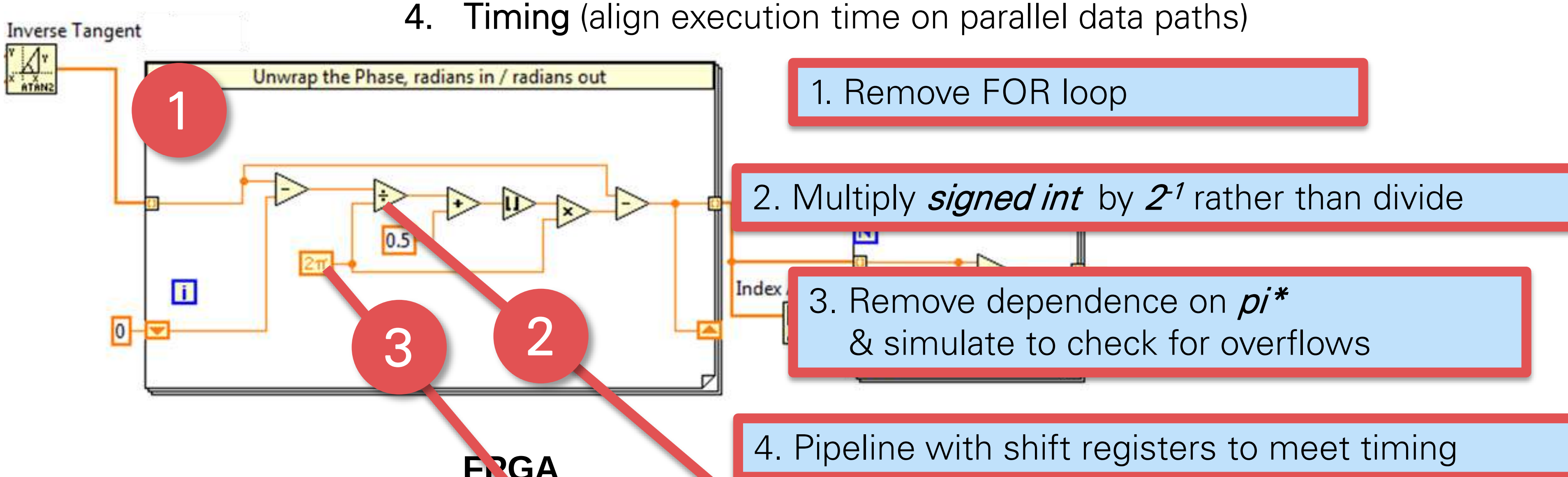

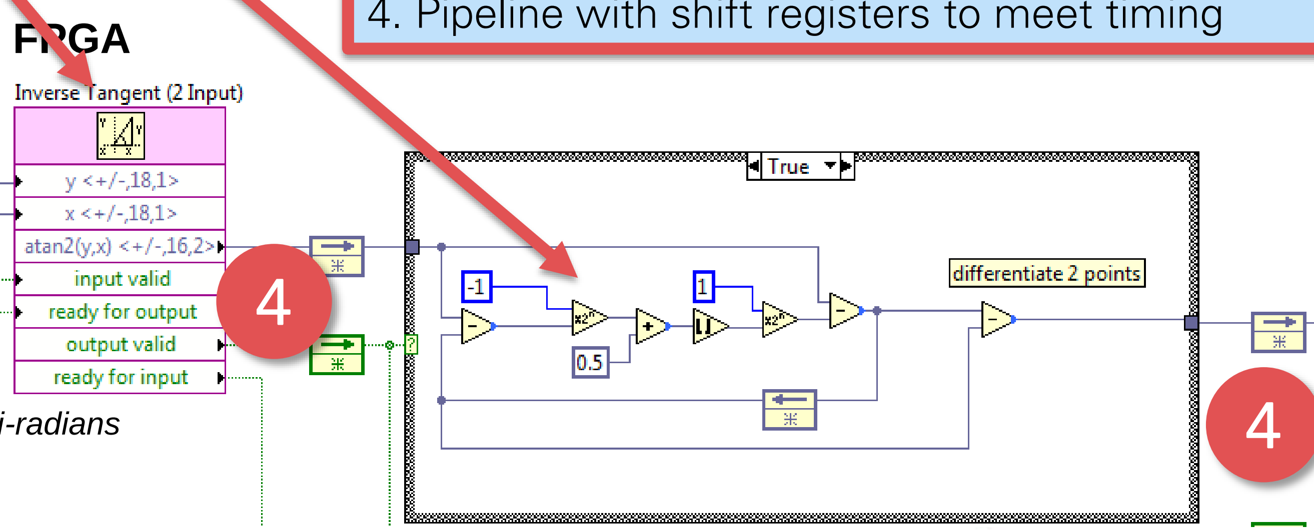

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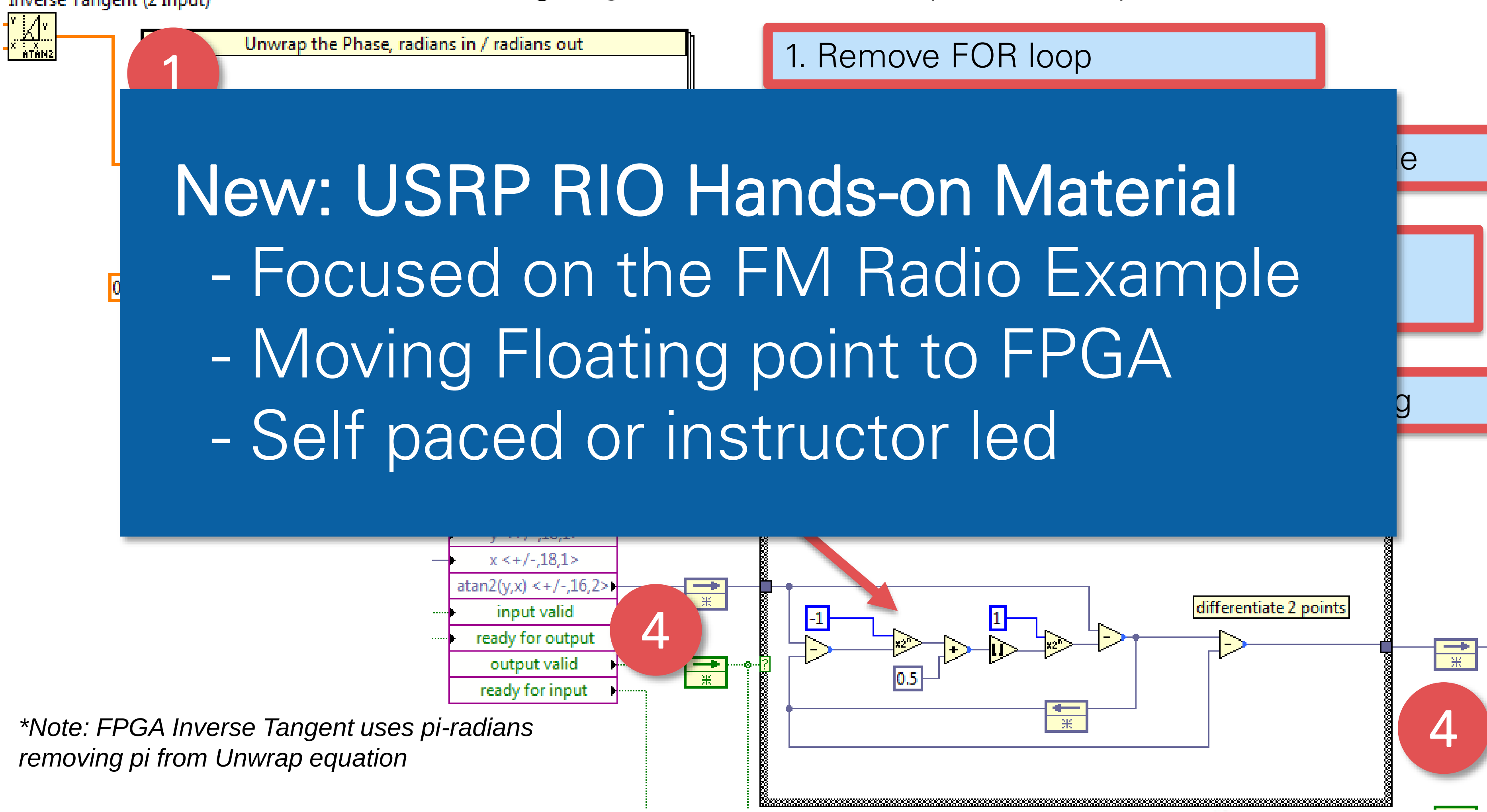
Host



New: USRP RIO Hands-on Material

- Focused on the FM Radio Example
- Moving Floating point to FPGA
- Self paced or instructor led

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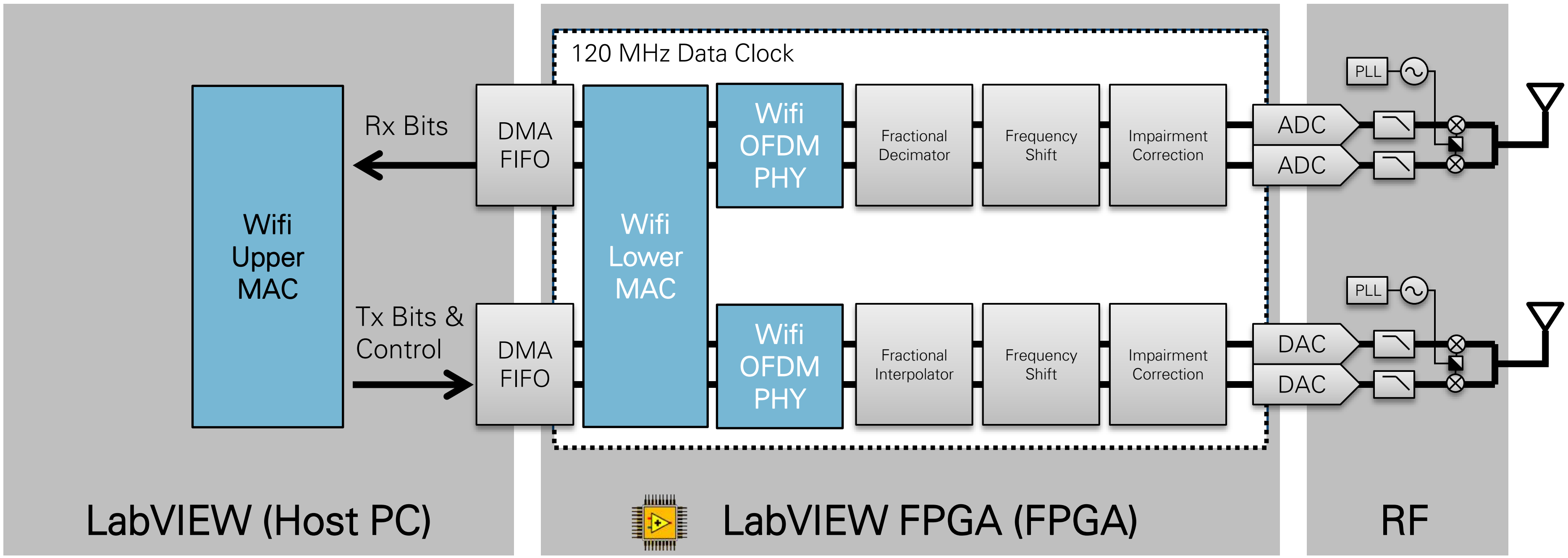
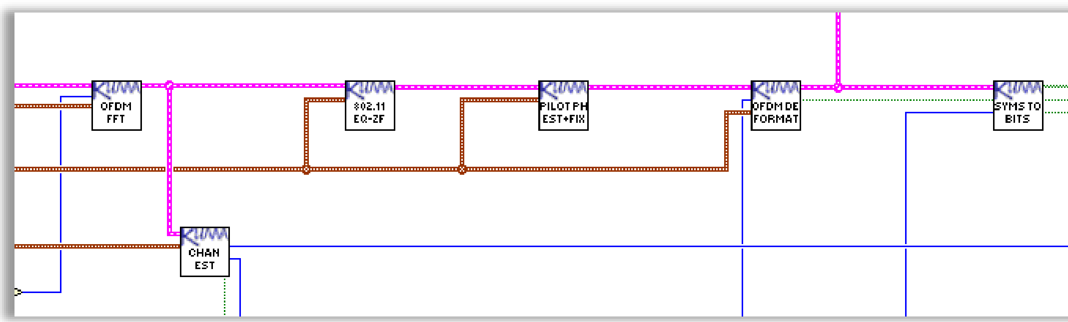
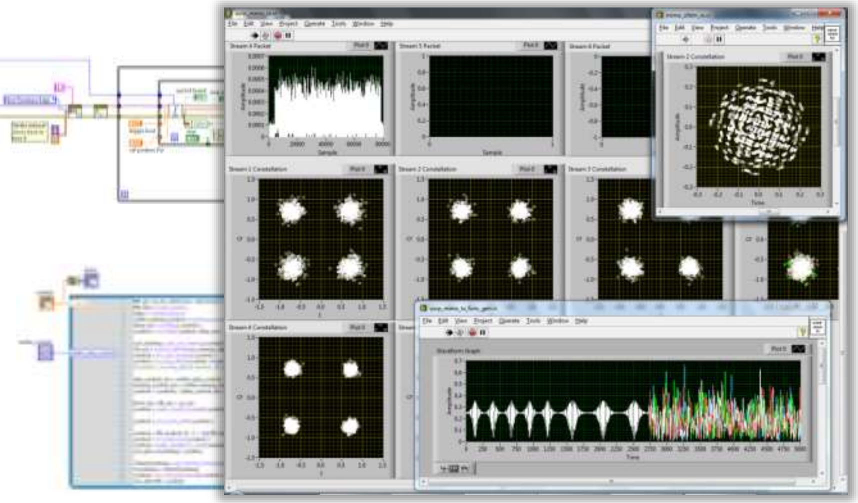
Example: OFDM Application Framework (Wifi-like)



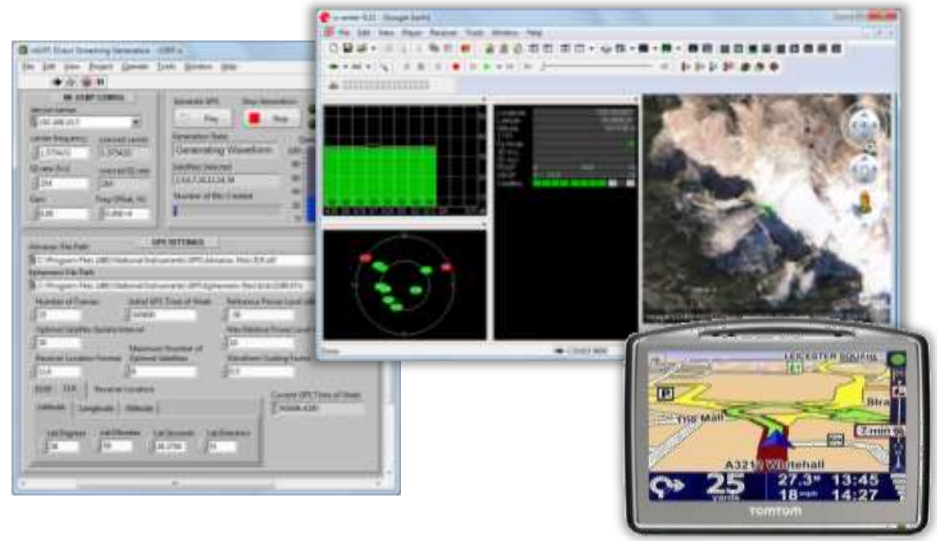
LV FPGA – Wifi OFDM PHY (RX)



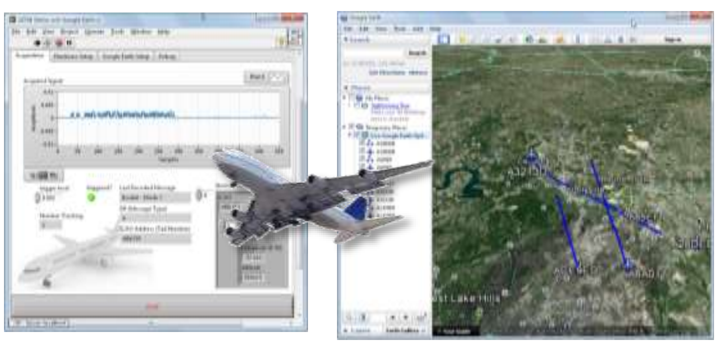
Community Contributed Reference Designs



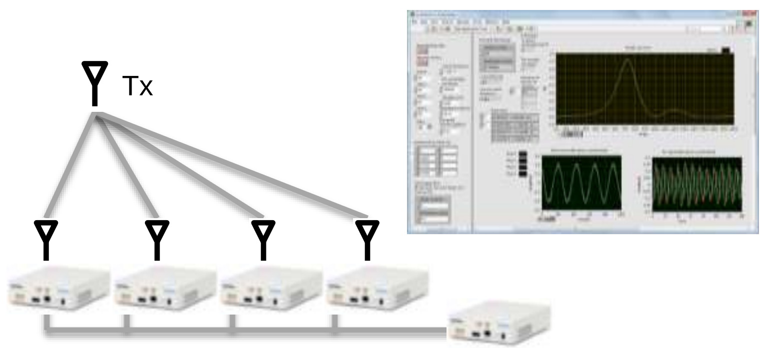
8x8 MIMO-OFDM



GPS Simulation



ADS-B Monitoring & Decoding



RF Direction Finding & Localization

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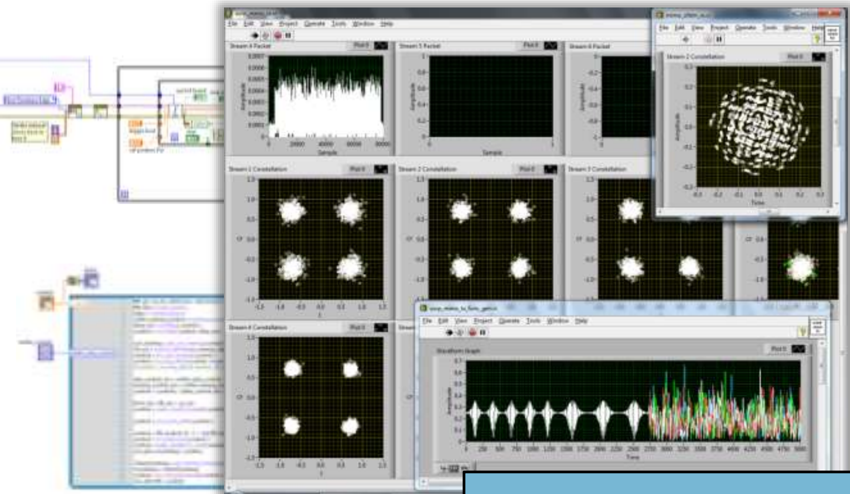
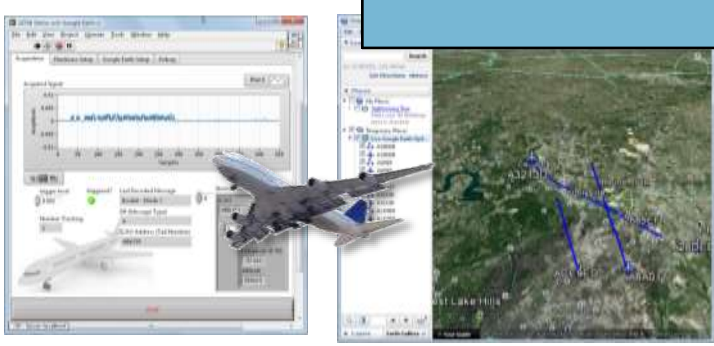


8x8 MIMO-OF

mulation

ni.com/sdr



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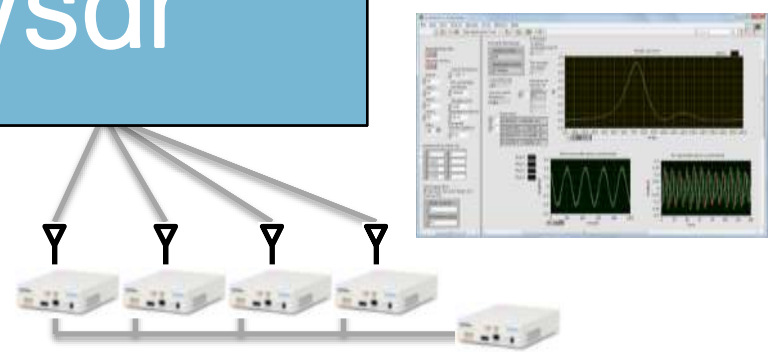
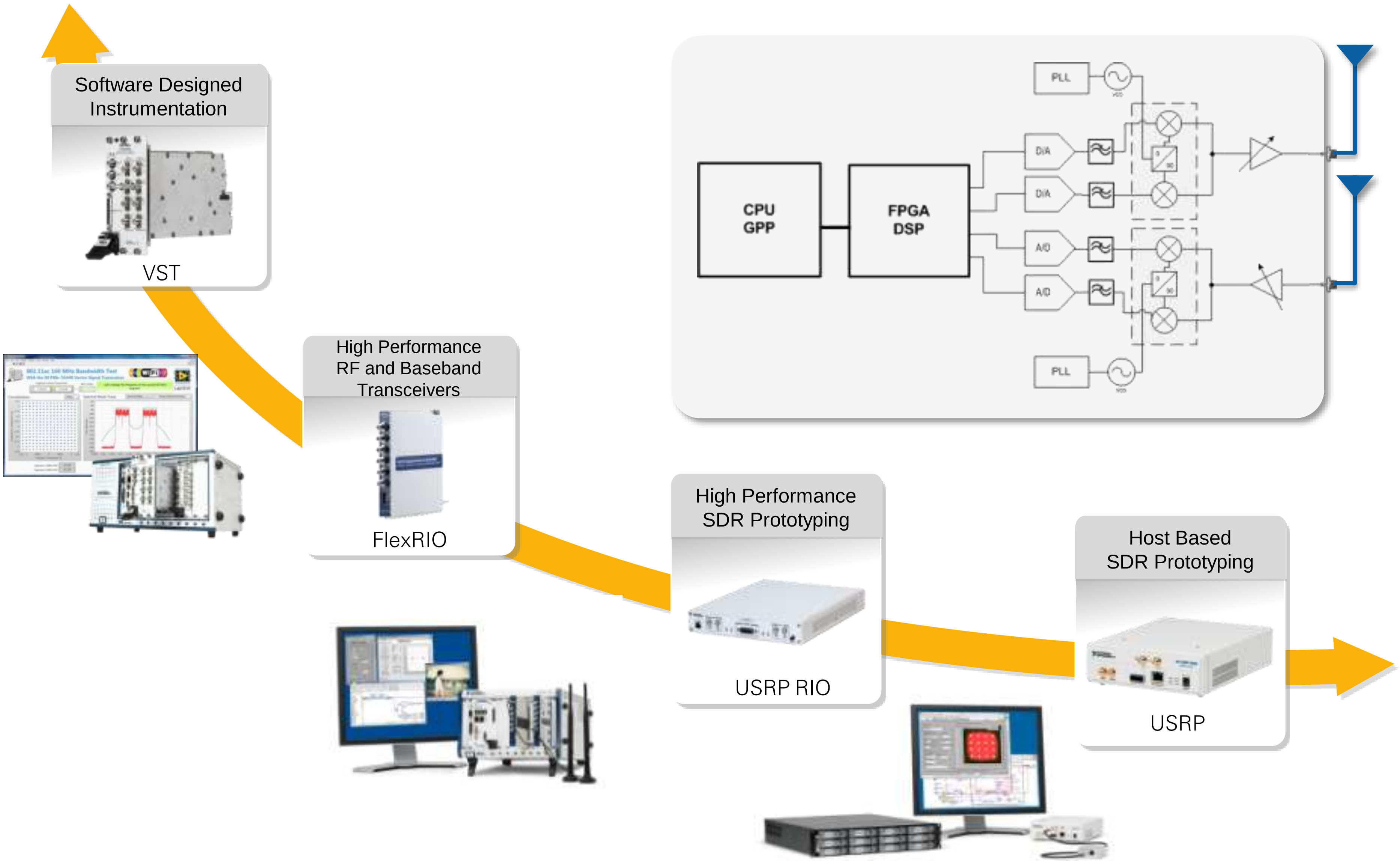


RF Direction Finding & Localization

Software Defined Radio Platform

Common Graphical System Design Tools



NI SDR Hardware Platforms

PXIe-564xR (VST) Features

- Frequency Range: 65 MHz to 6 GHz (aligned)
- **FPGA**: Virtex 6 LX195T
- Bandwidth: 200 MHz bandwidth
- Host I/F: PXIe x4 (~800 MB/s)
- Calibration: Factory, self calibration

FlexRIO, NI 579x Features

- Frequency Range: 200 MHz to 4.4 GHz (aligned)
- **FPGA**: Kintex 7 410T
- Bandwidth: 100 MHz / 200 MHz
- Host I/F: PXIe x4 (~800 MB/s)
- Calibration: Minimal, System

USRP RIO 294x/5x Features

- Frequency Range: 50 MHz to 6 GHz (coherent)
- **FPGA**: Kintex 7 410T
- Bandwidth: 40 MHz bandwidth
- Host I/F: PXIe x4 (~800 MB/s)
- Calibration: Minimal, System

USRP 292x/3x Features

- Frequency Range: 50 MHz to 6 GHz (coherent)
- **FPGA**: Host processing
- Bandwidth: 20 MHz bandwidth
- Host I/F: 1 Gb Ethernet (100 MB/s)
- Calibration: None, User

NI 579x RF Transceiver Adapter Module

NI 5791 Tx/Rx 100 MHz BW	NI 5792 Rx 200 MHz BW	NI 5793 Tx 200 MHz BW
• Rapid Prototyping • Wireless Link	• Spectrum monitoring • Advanced prototyping	• Wideband generator • Advanced prototyping

Features

- 200 MHz – 4.4 GHz RF Frequency
- Direct up and downconversion
- 130/250 MS/s, 14-bit input, 16-bit output
- 12 DIO for digital control

Target applications

- Software-defined radio (SDR)
- High-performance embedded systems
- MIMO / multi-channel, phase-coherent measurements
- Prototyping wide bandwidth next generation standards (802.11ac)

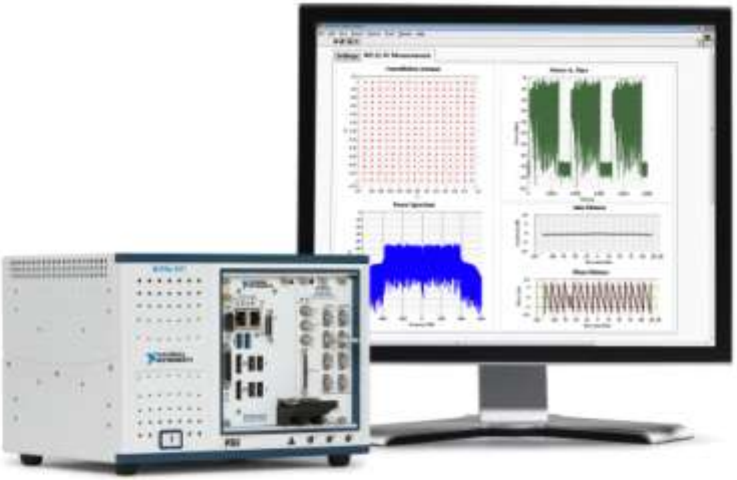
Vector Signal Transceiver

Specifications

- 65 MHz to 6 GHz frequency coverage
- Calibrated instrument with NIST traceability
- VSG & VSA with independent LOs
- 200 MHz instantaneous bandwidth
- 24 lines of DIO
- 3 Slot PXI Express module

Features

- Reprogrammable LabVIEW FPGA target
- Support for MIMO configurations
- Low-cost, small footprint
- Industry-leading measurement performance for the latest RF standards such as 802.11ac and LTE

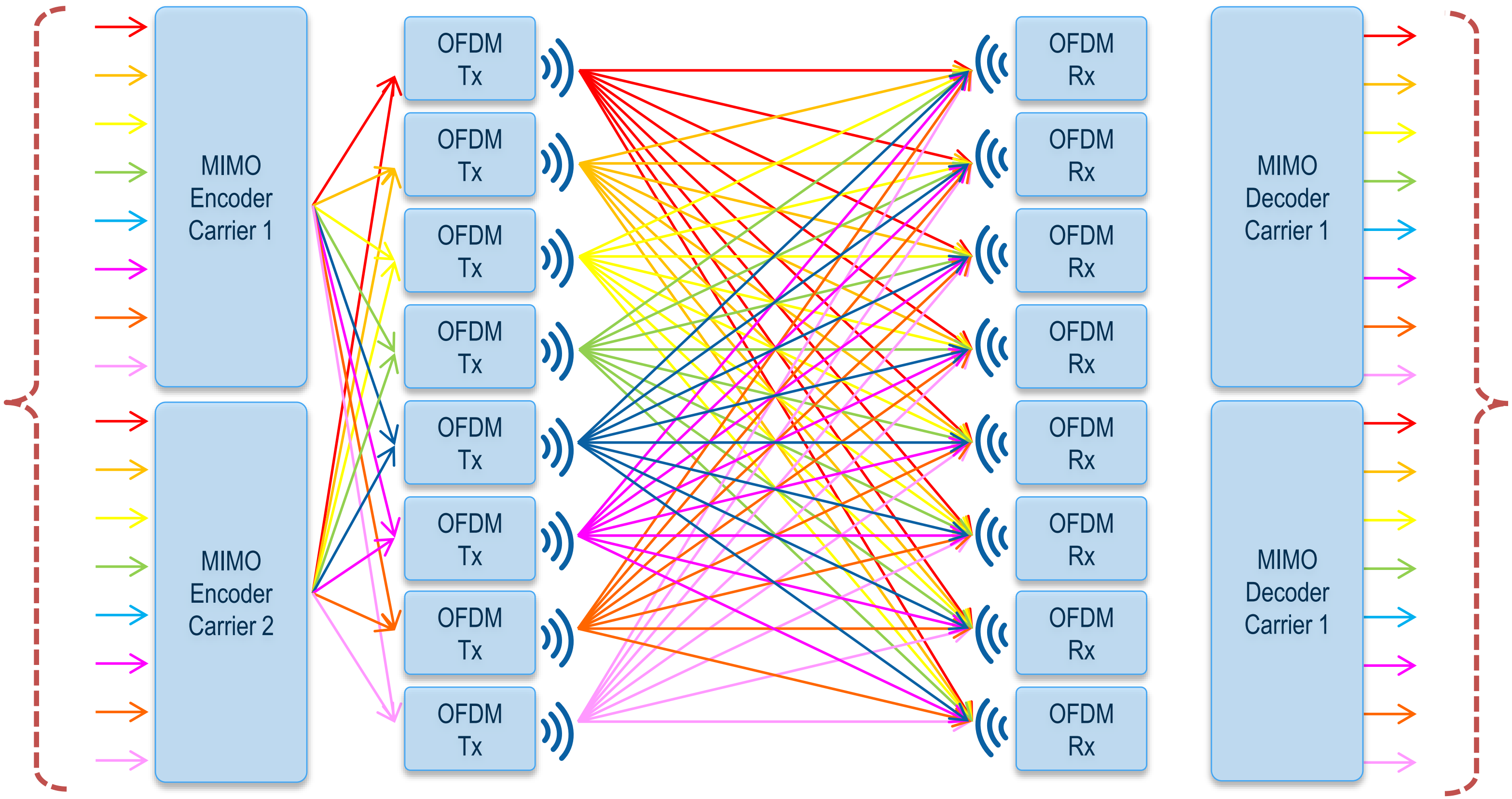


Applications

- Channel emulation
- High performance RF test (RF Standards)

NATIONAL INSTRUMENTS

2011: World's First LTE-Advanced 8x8 MIMO
Demonstration



8x8 MIMO Wireless Channel
1 Gigabits per second!

Demonstrated
at NIWeek 2011

NI and TU Dresden Collaborate on 5G Wireless

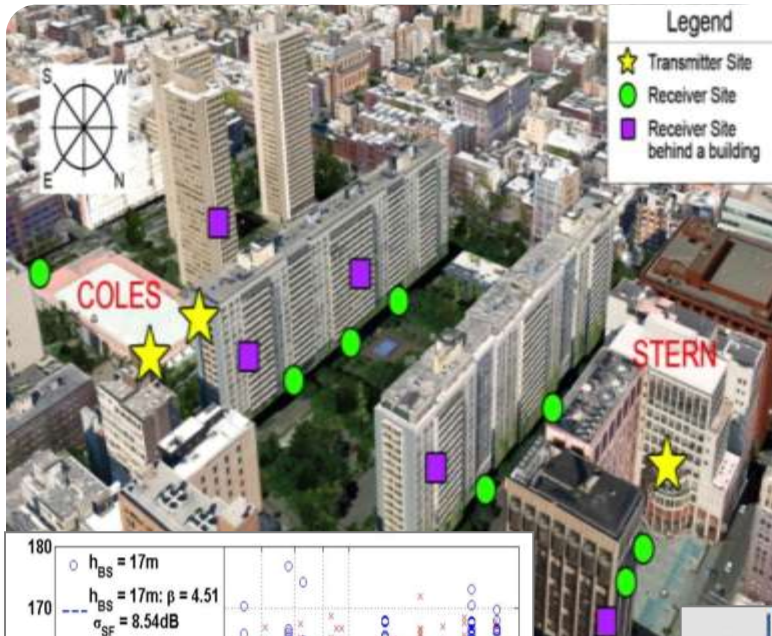
Dr. Gerhard Fettweis

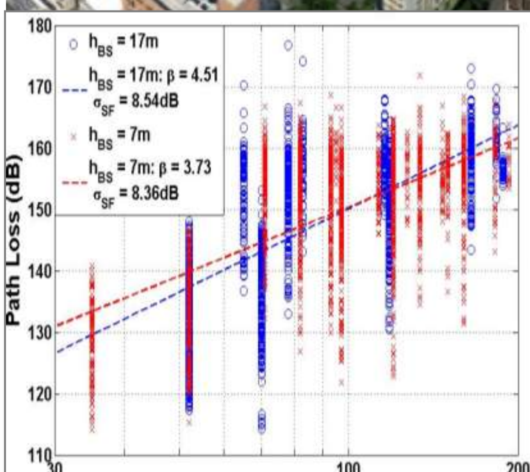
TECHNISCHE UNIVERSITÄT DRESDEN

- 5G Lab and Test Bed
- 5G PHY exploration and prototyping
- Using LabVIEW Graphical System Design

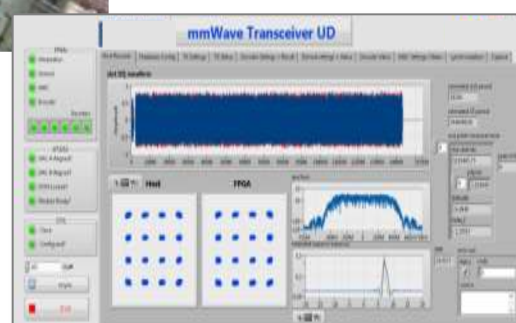
NI and NYU Poly Collaborate on 5G Wireless

NYU·poly
POLYTECHNIC INSTITUTE OF NYU





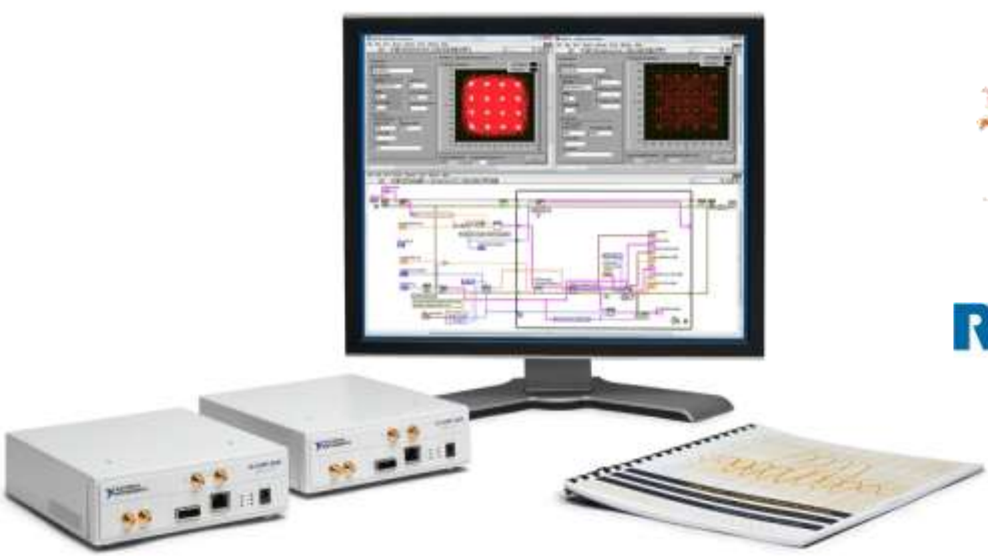
- Channel sounding at 28, 38, and 72 GHz
- Prototype system uses NI FlexRIO and LabVIEW software



Prof Ted Rappaport

NATIONAL INSTRUMENTS

Teaching Next Generation of Wireless Engineers



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Teaching Next Generation of Wireless Engineers

STANFORD UNIVERSITY

"The course evaluations for our class were fantastic! **Students rated the class 4.94/5.0**, likely making it one of the **highest rated among all classes** in the School of Engineering at Stanford."
–Dr. Sachin Katti, Stanford University

"Hands down the best EE class I've taken so far."
–Student

"Awesome class! I really enjoyed the lectures, and the labs were really cool because we got to use the hardware."
–Student

Summary

- 5G is coming, but there is a lot of work to do.
- It will be prototyped with Software Defined Radio.
- The right tools can accelerate innovation.

Learn more at: ni.com/sdr