NATIONAL INSTRUMENTS™

Biography

Dr. James Truchard
President, CEO, and Cofounder

James Truchard, president and CEO, cofounded National Instruments in 1976 and has pioneered the way scientists and engineers solve the world's grand engineering challenges

National Instruments now has presence in over 50 countries and annual revenues of $1.2 billion. Dr. Truchard is an IEEE Fellow, a member of the National Academy of Engineering, a member of the Royal Swedish Academy of Engineering Sciences.

Truchard holds a doctorate in electrical engineering, as well as a master's degree and bachelor's degree in physics, all from the University of Texas at Austin

COTS Platform-Based Design For Spectrum Monitoring & Signal Intelligence

Dr. James Truchard

President, CEO, and Cofounder
National Instruments

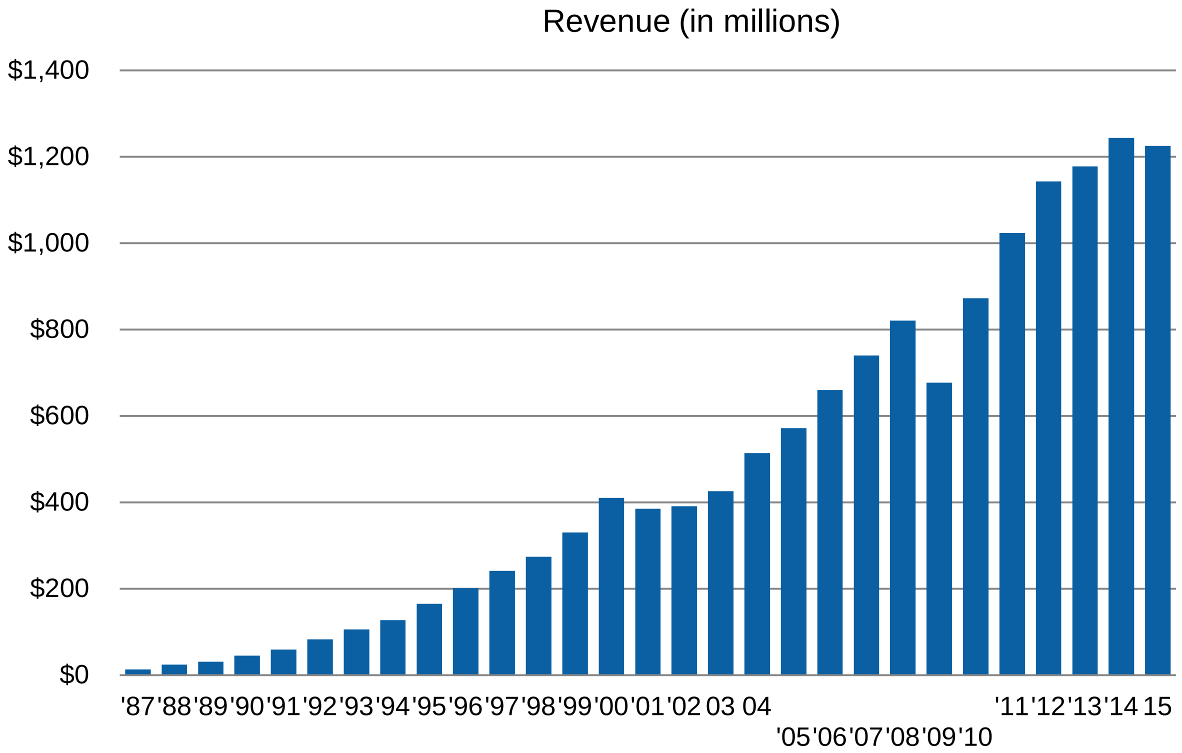
Long-Term Track Record of Growth

Revenue: $1.23 billion in 2015

Global Operations: Approximately 7,300 employees; operations in 60 countries

Broad customer base: More than 35,000 companies served annually

Diversity: No industry >15% of revenue



The Role of a Platform

Are you wearing a watch?

A Platform Revolutionizes Your Approach to Solutions

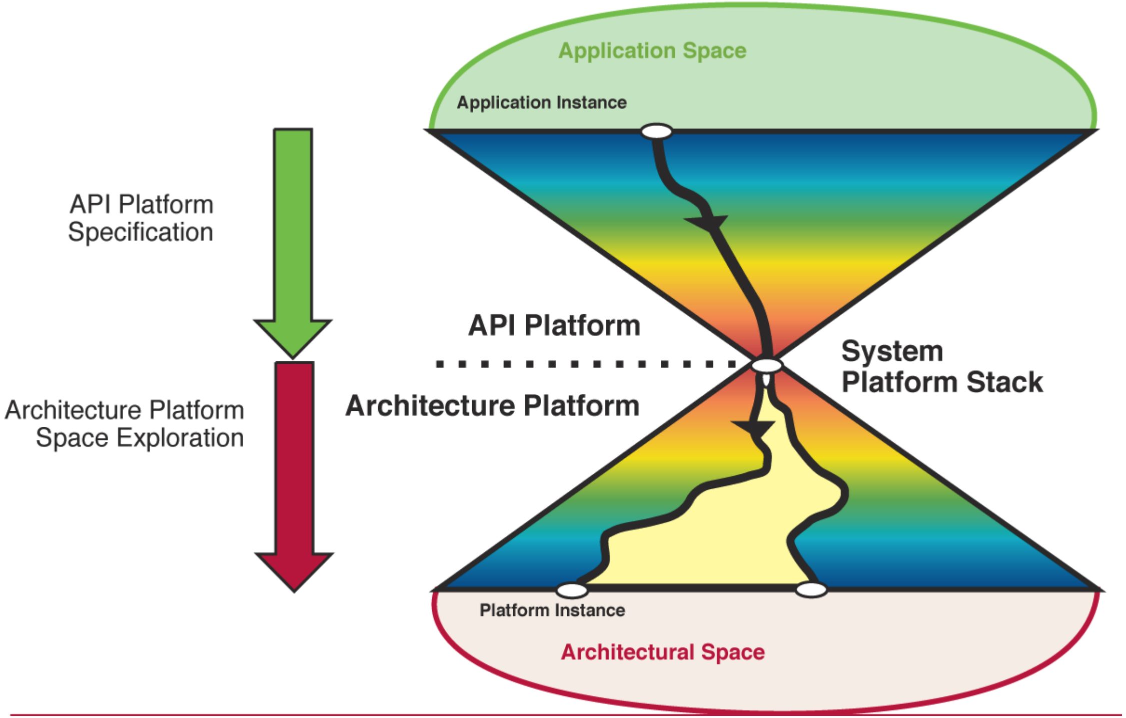
NATIONAL INSTRUMENTS

Why Do Ecosystems Win?

- 1.25 Million Apps
- 1,000 new/day

NATIONAL INSTRUMENTS

Platform-Based Design for Communications Systems

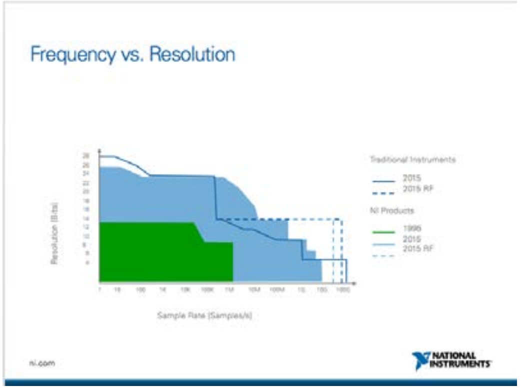


A. Sangiovanni-Vincentelli, UC Berkeley. Defining Platform Based Design. EEDesign, Feb 2002

Three Pillars of Differentiation

Differentiation of our Software and Hardware Platform

Leveraging Moore's Law



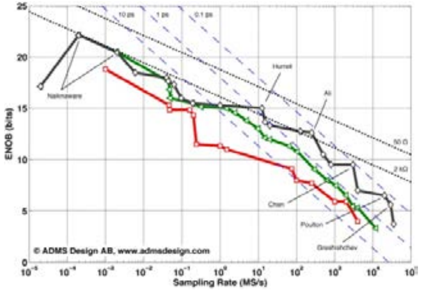
Growth of the Ecosystem

Ecosystem

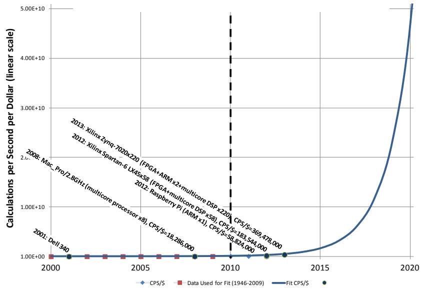
- *User Community*
- *NI Support*
- *NI Channel*
- *Partners*
- *3rd Party HW & SW*
- *NI Services*

Moore's Law & Commercial Technology Investments Driving Platform Value

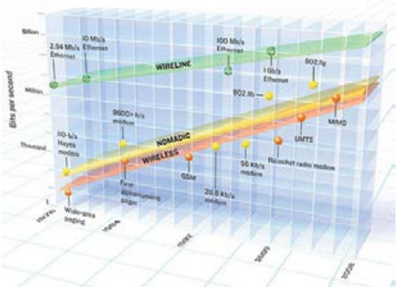
ADCs / DACS



CPUs / FPGAs



RF Components



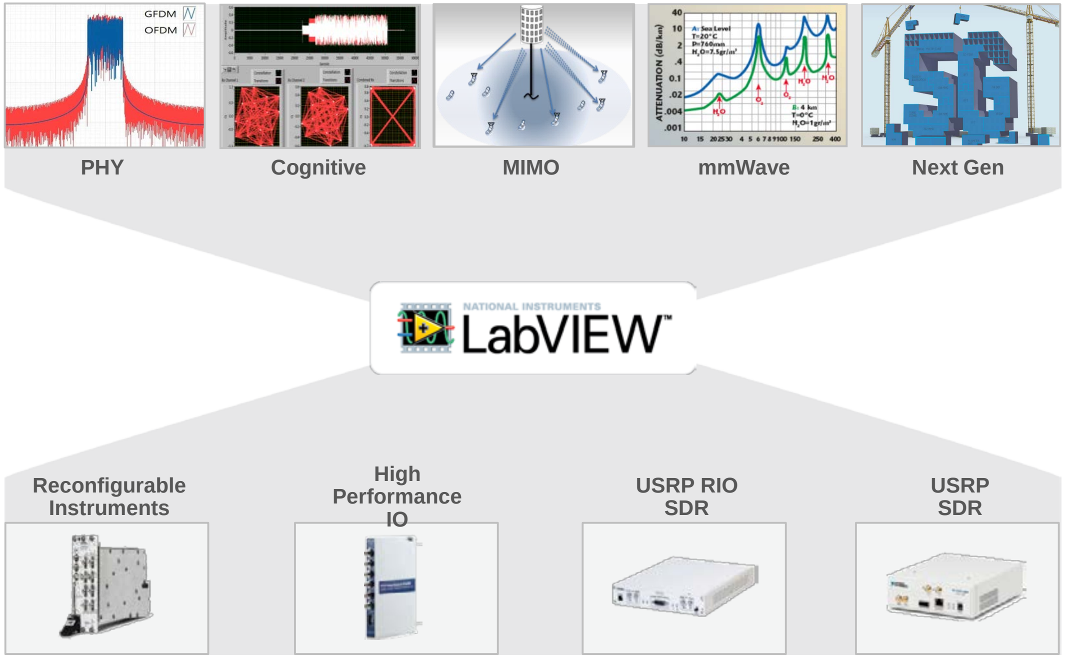
Continuous investment in our Platform

NATIONAL INSTRUMENTS LabVIEW™

30 Years
~ 20,000 Man-Years

NATIONAL INSTRUMENTS

Platform Based Design for 5G



Platform Based Design – Beyond Math

Design → Prototype → Deploy

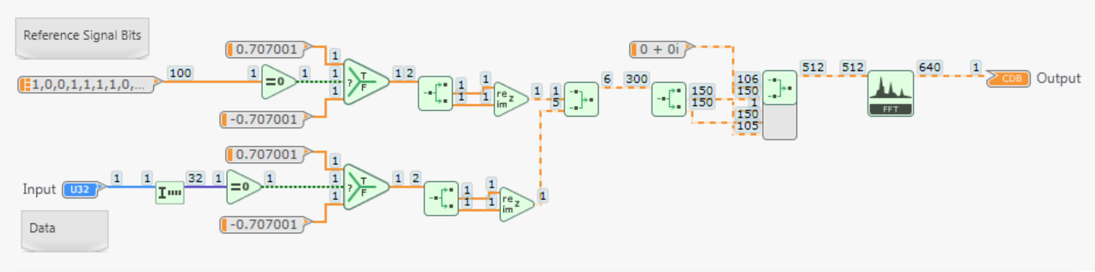
Algorithm Design + Prototyping

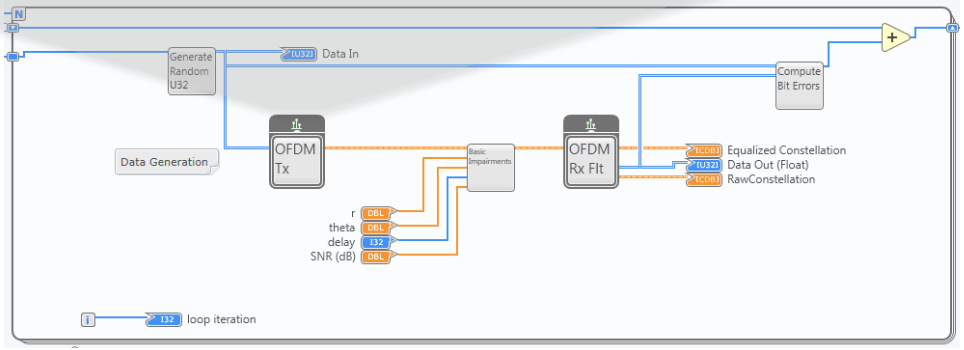
=

Algorithm Engineering

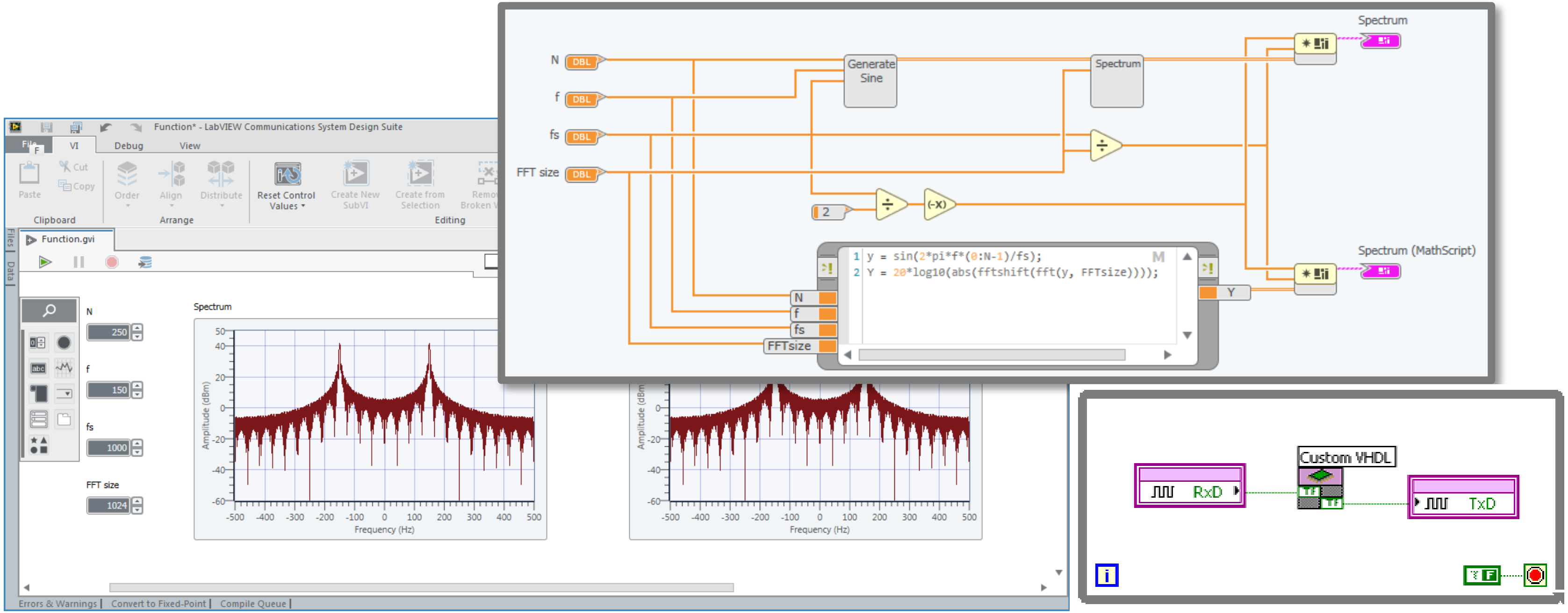
UC Berkeley		The LabVIEW Dataflow Platform
Berkeley SPICE1	1972	
	-	
EDA Design Tools – Synopsys (1986) • Cadence (1988)	1980	
	-	
Synchronous Dataflow	1986	**LabVIEW 1.0**
	-	
Ptolemy I	1990	LabVIEW Compiler
	-	
Boolean Dataflow • Multidimensional SDF	1993	
Integer Dataflow	1994	
Bounded Dynamic Dataflow	1995	
Ptolemy II	1996	
Heterochronous Dataflow	1997	LabVIEW Multithreading
	1998	LabVIEW Real-Time Module
	-	
Giotto	2001	
	-	
	2004	LabVIEW FPGA Module
	-	LabVIEW Control Design and Simulation Module
	2006	
	2007	LEGO® MINDSTORMS® NXT-G
	2008	LabVIEW MathScript
	2009	LabVIEW Statechart Module • LEGO® Education WeDo™
PRET	-	
	2011	
	-	LabVIEW FPGA IP Builder LabVIEW DSP Design Module
	2014	Multirate Diagram

Combination of a Turing Complete Dataflow Language with Synchronous Dataflow



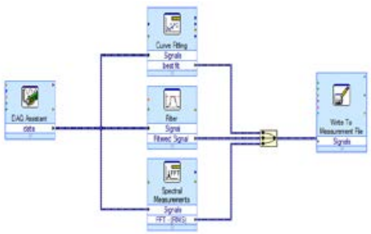


The Hybrid Approach
Combined Graphical / Textual Programming

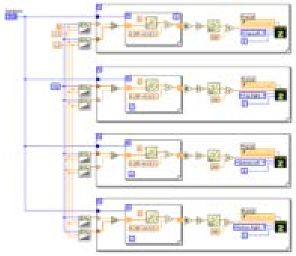


NATIONAL INSTRUMENTS

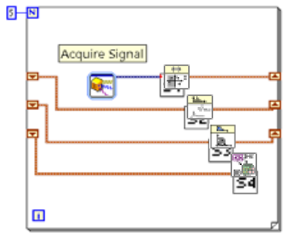
Parallel Programming with LabVIEW



Task Parallelism

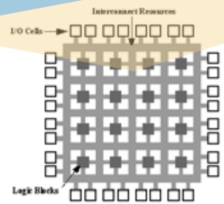


Data Parallelism



Pipelining

Multicore Processors



FPGAs

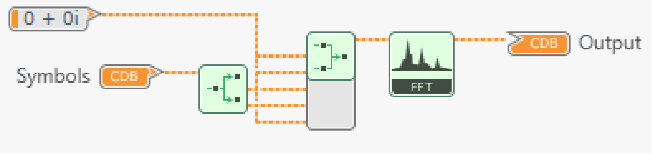
Platform Enabled Design Flow

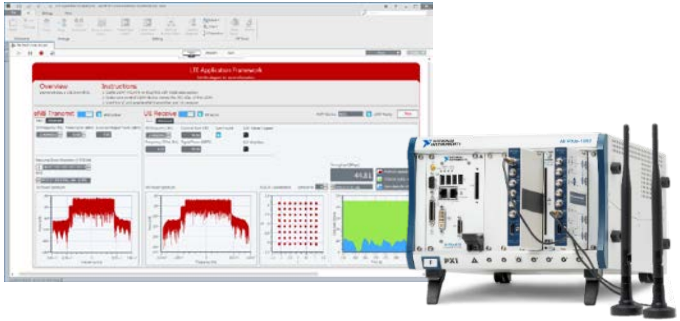
Algorithm Development → System Mapping → System Implementation → Algorithm running on prototype

Heterogenous Multi-Processing Including FPGA's

Collaborative Design Team or Single Design Team

Single, Cohesive Toolchain

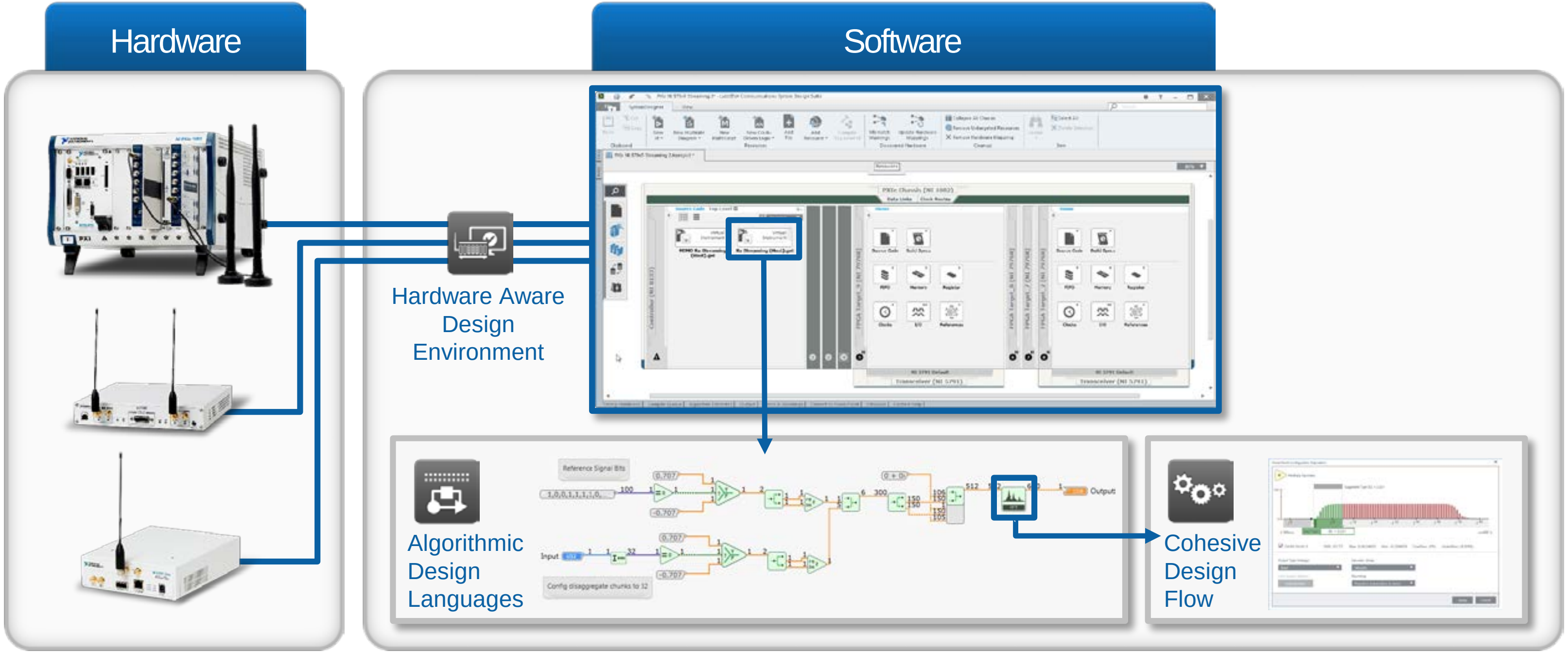




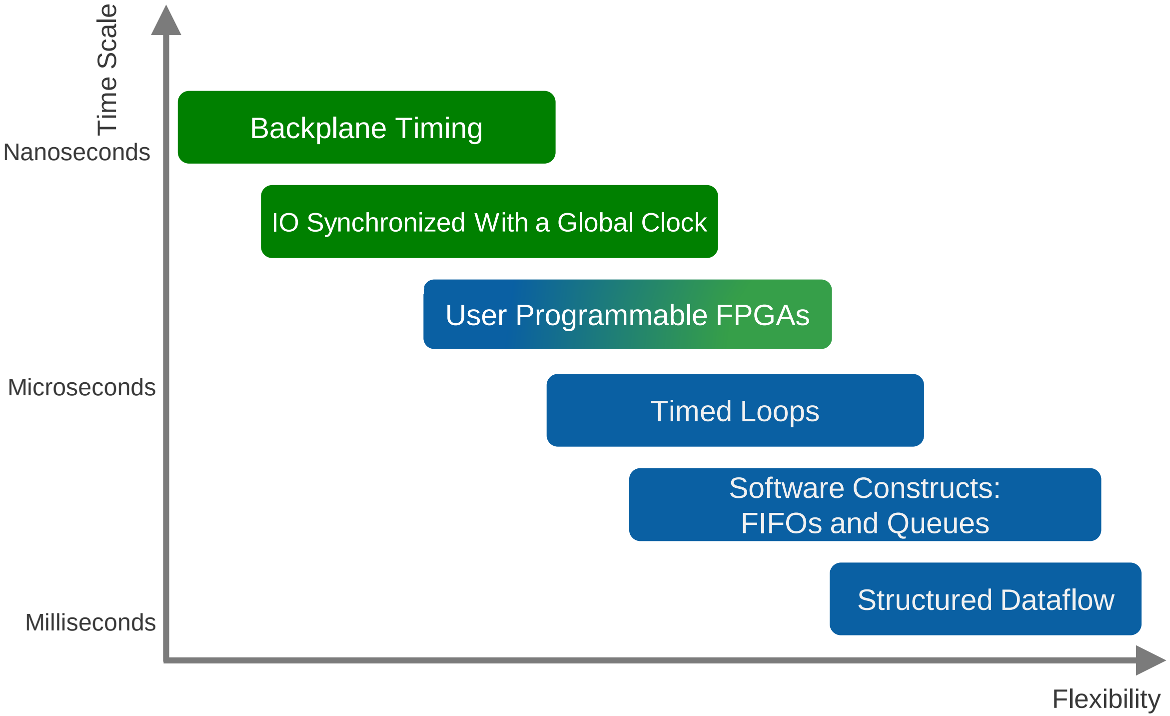
NATIONAL INSTRUMENTS

LabVIEW Communications System Design Suite

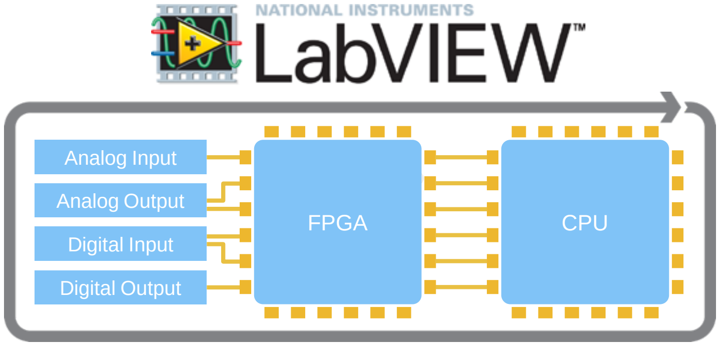
The Revolution in Rapid Prototyping

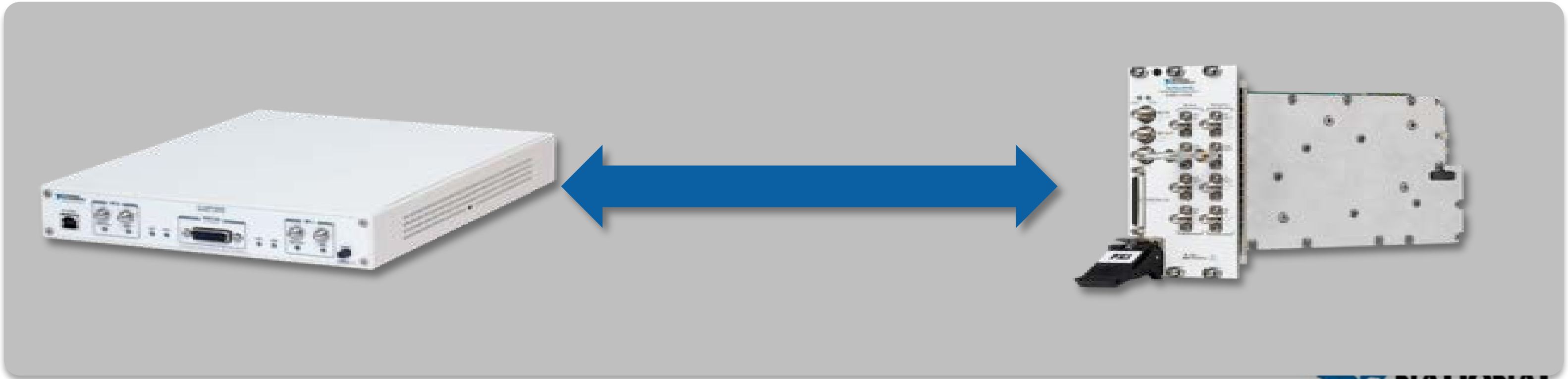


Technologies for Time and Concurrency



One Common Underlying Architecture





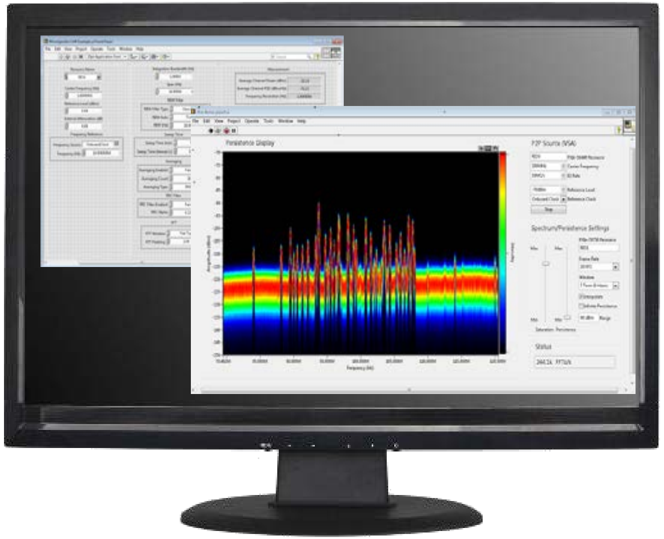
Microwave Product Suite - Software

Driver Software

RFSA, RFSG & RFmx
Toolkits
Software Ease of Use
Fast Measurements

FPGA Extensions

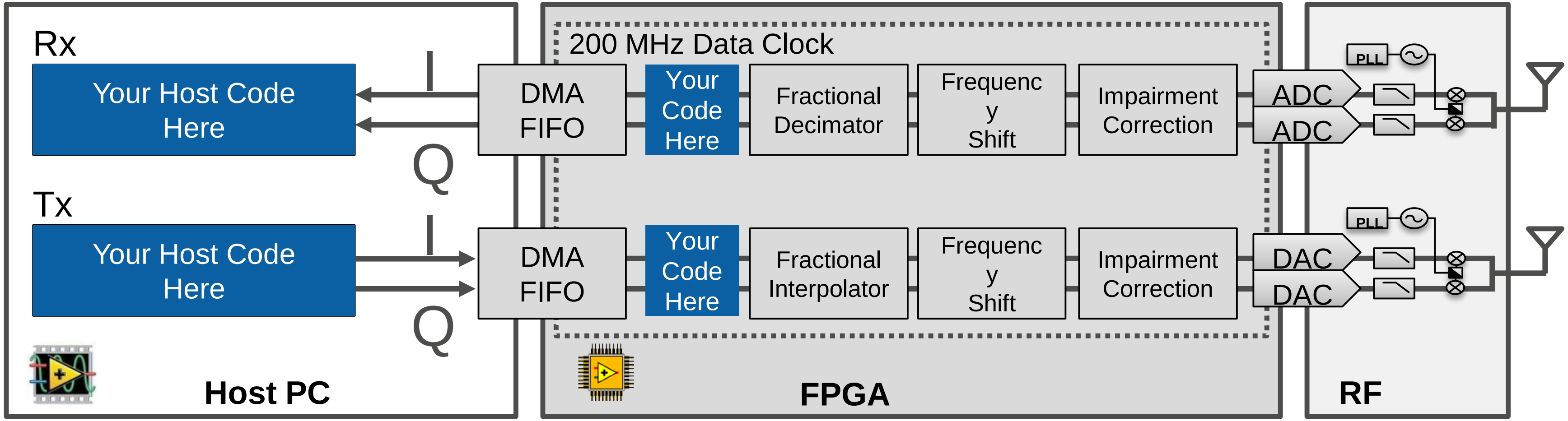
Real-Time Spectrum Analysis
Streaming and Synchronization

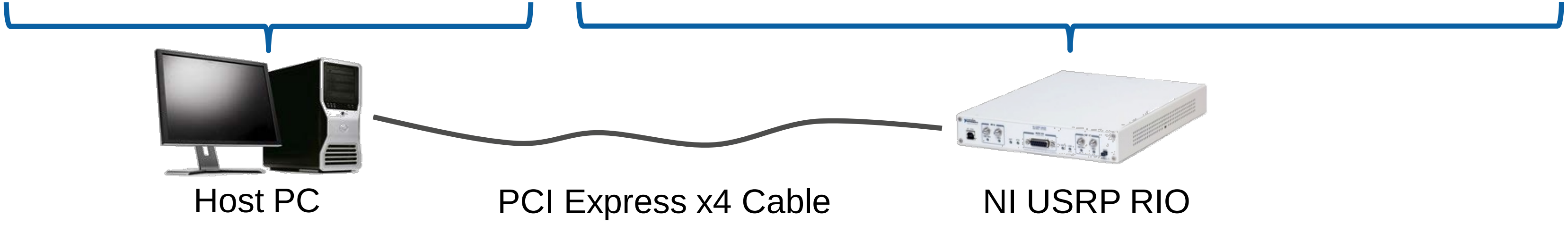


SFP Support

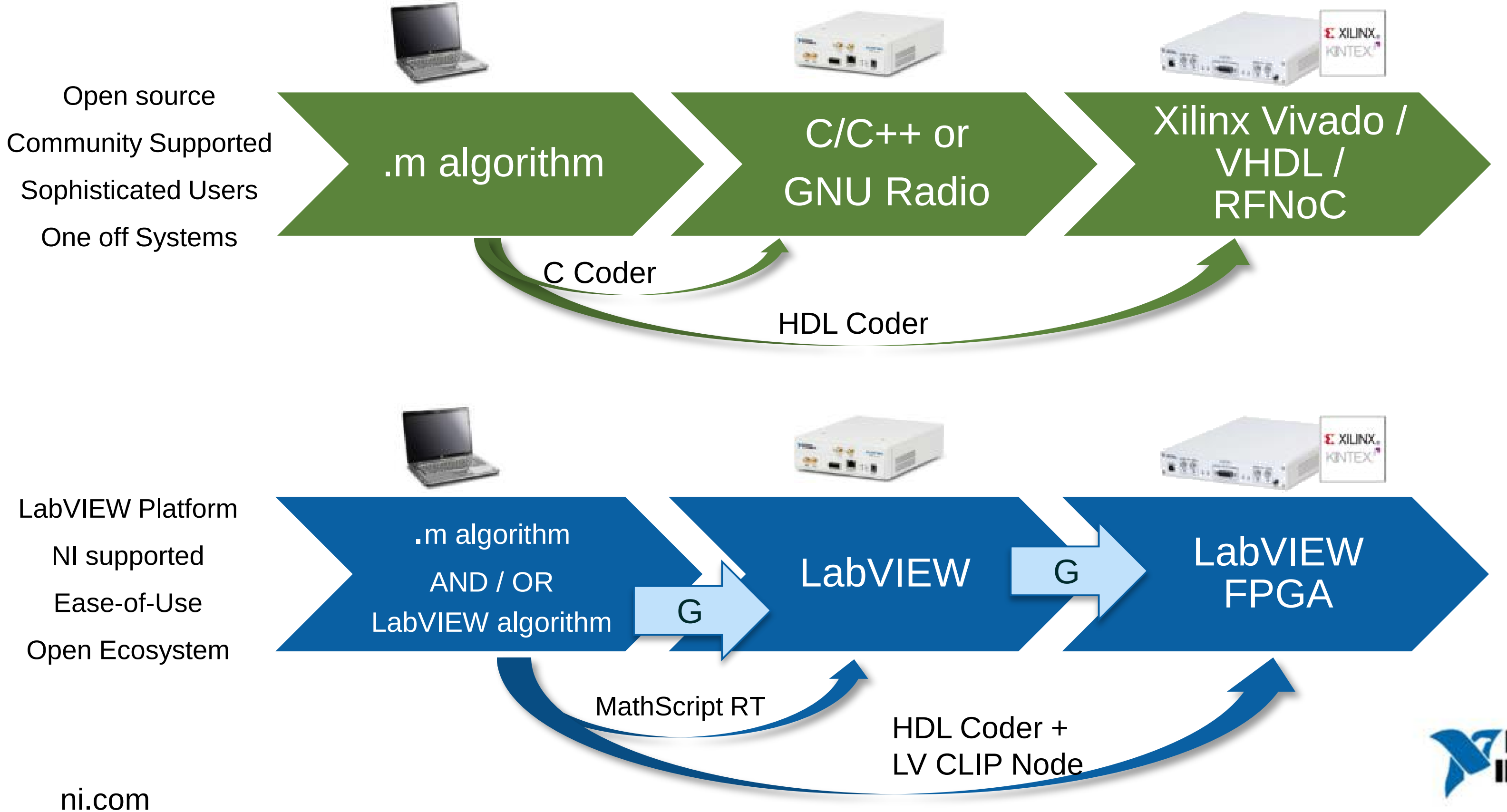
Spectrum Analyzer Software
Debug features
RF Measurements

NI USRP RIO Driver Software (Host + FPGA)

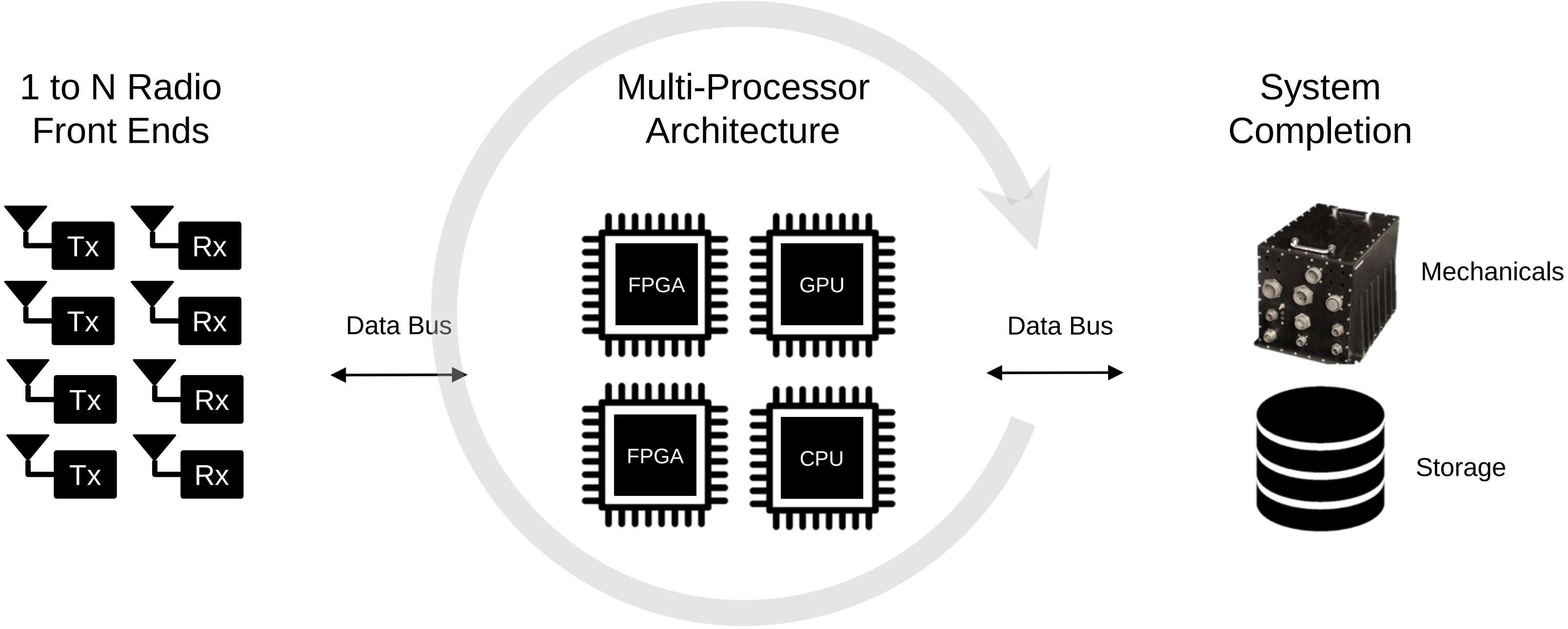




Typical Design Flows



Elements of a Spectrum Monitoring System

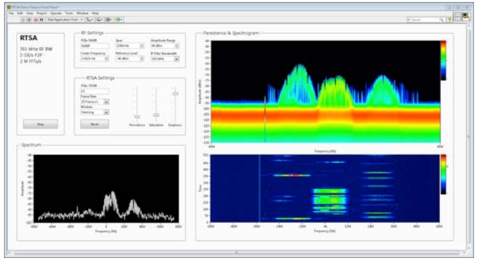


Hardware is Commoditized

Software is Hard!!!

Storage is Commoditized

Spectrum Monitoring System Considerations



Receiver Performance

- Scan Rate
- Preselection & Dynamic Range
- Linearity (SHI and TOI)
- Noise Figure / Sensitivity

Signal Processing

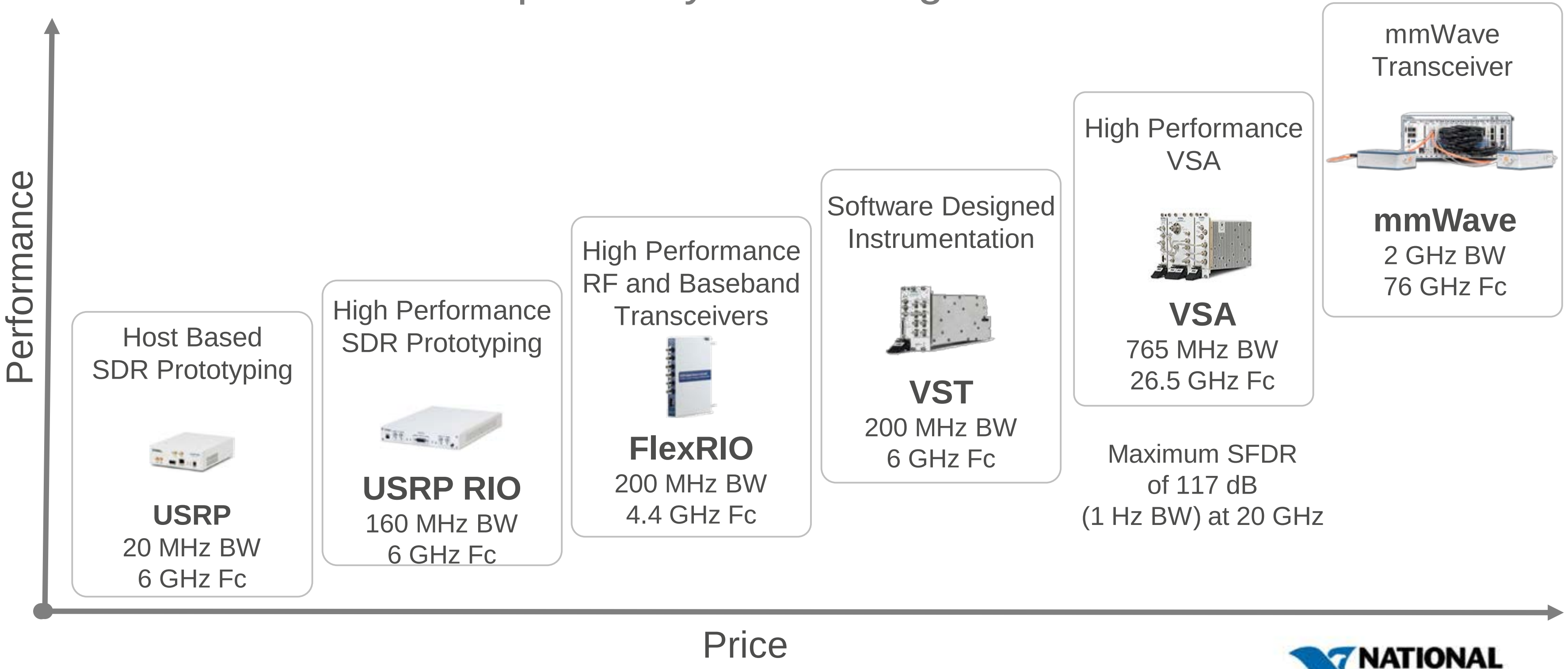
- Modulation/Signal Recognition
- Digital downconversion/channelization
- Filtering and windowing functions

System Completion

- Transportable (SWAP)
- Graphical display
- Data storage and playback
- Multi-channel and multi-system synchronization and GPS time stamping

Scalable Platform for RF and Wireless Communication

Common LabVIEW Graphical System Design Software



NATIONAL INSTRUMENTS

Spectrum Monitoring / SIGINT Product Portfolio

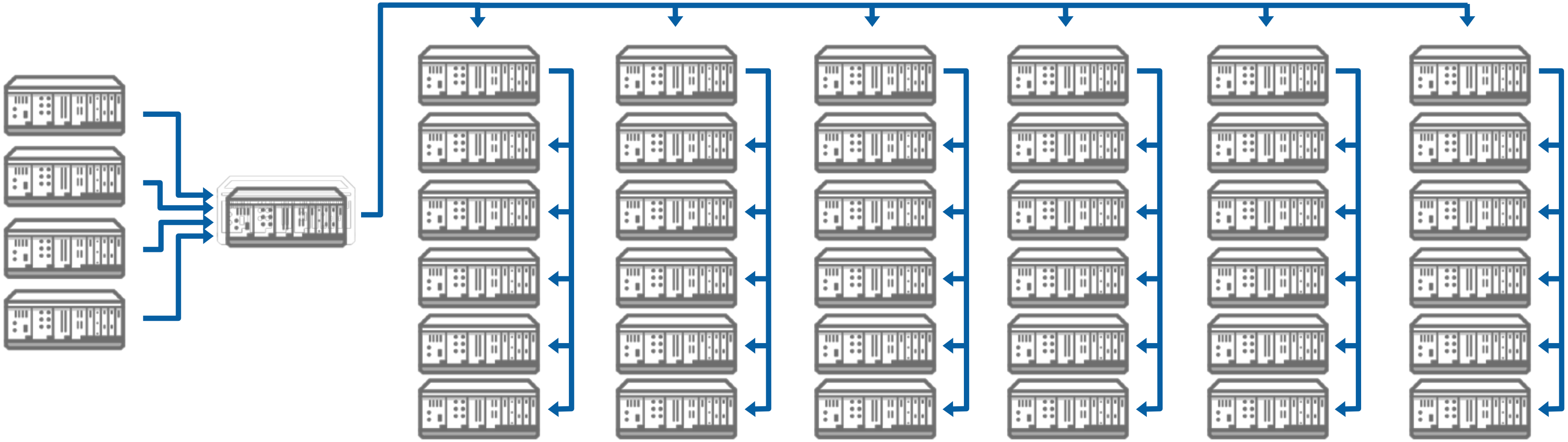
	E310	USRP-RIO	FlexRIO	VST	PXIe-5668R	Bee7
Signal Processing (TMACs)	0.276	2.8	2.8	1.2 (native) Expandable to 41.0	2.8 (native) Expandable to 31.3	21.3 (native) Expandable to 127.8
Maximum SFDR	66 dB	80 dB	106 dB	110 dB	120 dB	58 dB
Analog Bandwidth	56 MHz	120 MHz	200 MHz	200 MHz	765 MHz	2 GHz (IF BW)
Specification Type	Characteristic	Characteristic	Characteristic	Guaranteed	Guaranteed	Characteristic
Shock & Vibration		30 g peak shock 0.3 g_{rms} vibration	30 g peak shock 0.3 g_{rms} vibration	30 g peak shock 0.3 g_{rms} vibration	30 g peak shock 0.3 g_{rms} vibration	
Volume	239 cm^3	2,365 cm^3	1,349 cm^3	40,743 cm^3 (18 slot chassis)	40,743 cm^3 (18 slot chassis)	122,379 cm^3 (14 slot chchassis)
Channels per System	2 Rx per module	2 Rx per module	1 per module	5 per chassis	3 per chassis	1 (2 GHz BW)
Example Applications	Spectrum recording	RTSA and Multi-channel DDC	RTSA and Multi-channel DDC	4x4 Digital channel emulator	Blind detection and real-time demod	Prototype eNB with full protocol stack

LabVIEW

GNU Radio

NATIONAL INSTRUMENTS

Ultra High Performance Computing
For Real-Time Streaming Applications



40TB/s Processed

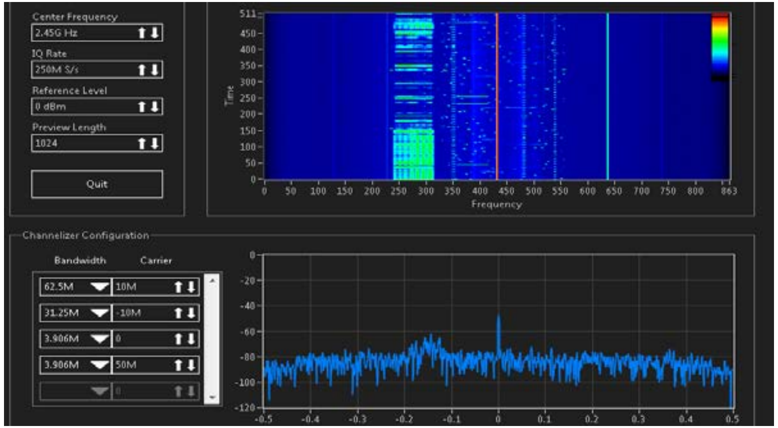
50µs Cycle Time

400FPGA Modules

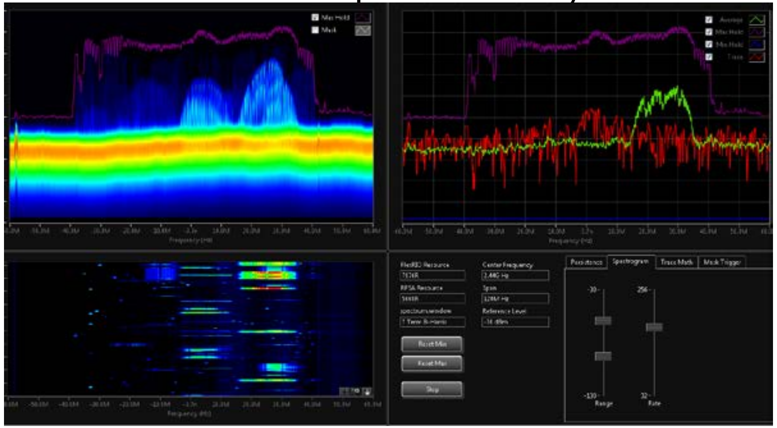
NATIONAL INSTRUMENTS

High Performance Real-Time Spectral Analysis Using LabVIEW FPGA

Channelizer DDC



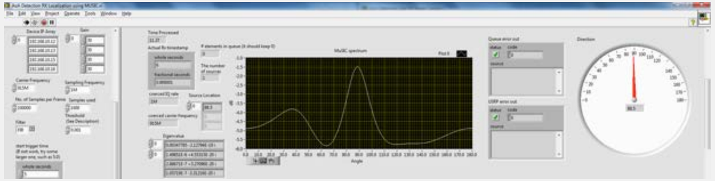
Real-Time Spectrum Analyzer

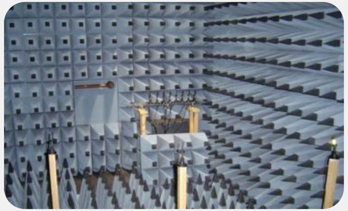


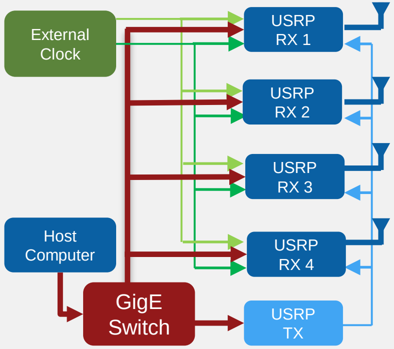
- Pipelined Frequency Transform (PFT) based
- Up to 512 independent channels
- Variable bandwidths and center frequencies
- Total channelization bandwidth 100 MHz

- Persistence & Spectrogram Display
- Custom Mask Trigger
- Integrated record to disk capability
- < 1.5 us POI (5668R)

Angle of Arrival Detection: MUSIC Algorithm







Calibration Signal

Testing MUSIC direction finding algorithm

- Rapid prototyping in LabVIEW with MathScript RT
- Synchronized up to12 USRP devices
- Reference provides continuous phase alignment compensation

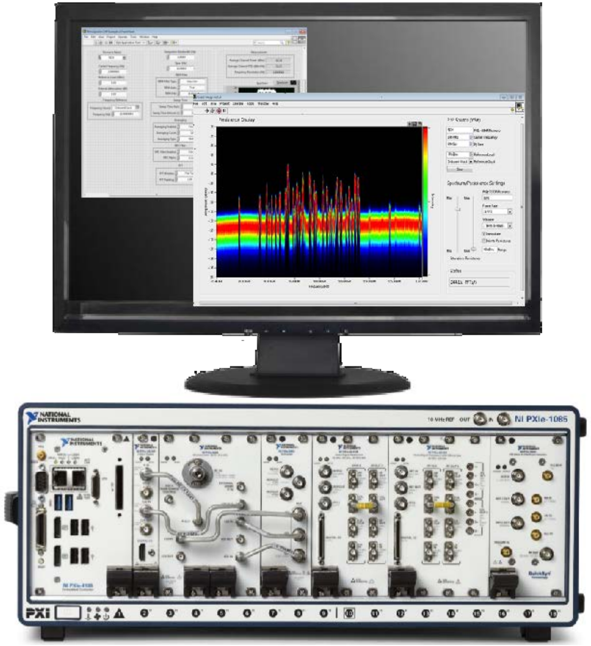
Marc Willerton, Imperial College London, Communications and Signal Processing Group

Imperial College London

NATIONAL INSTRUMENTS

Radio Monitoring System

- Frequency Coverage: **20MHz – 7GHz**
- Real Time Bandwidth: **300MHz**
- RF Scanning at **100GHz/s**
- RF Analysis using **512 channelizer, RTSA and Automatic Modulation Classification**
- RF record & playback @ **300MHz**
- RF Localization with **5 channel RF channels using correlative interferometry / MUSIC algorithm with accuracy of <1 degree**



NATIONAL INSTRUMENTS

PXI 5G Implementation

mmWave Cellular

NOKIA docomo

Platform Capability:
Up to 2 Antennas
2 GHz BW
Up to 110 GHz Frequency
>10 Gbps Throughput

Implemented Today:
Up to 2 Antennas
2 GHz BW
72 GHz Frequency
10 Gbps Throughput

Massive MIMO

LUND UNIVERSITY KU LEUVEN

Platform Capability:
Up to 256 Antennas
Up to 160 MHz BW
Up to 6GHz Frequency
>10 Gbps Aggregate Throughput

Implemented Today:
100 Antennas
20 MHz BW
Up to 6GHz Frequency
1 Gbps Aggregate Throughput

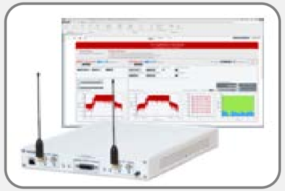
Dense Networks/ New Waveforms

TECHNISCHE UNIVERSITÄT DRESDEN 5GNOW

Platform Capability:
Up to 2 Antennas
Up to 160 MHz BW
Up to 6GHz Frequency
>1 Gbps Throughput

Implemented Today:
2 Antennas
20 MHz BW
Up to 6GHz Frequency
>1 Gbps Throughput

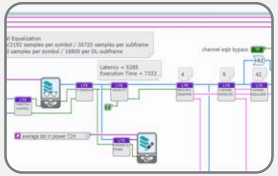
LTE, 802.11and Massive MIMO Application Frameworks



Real-time wireless system implementation

Ready to run PHY and basic MAC

Communicate between devices or in loop-back mode



Open and Modular Source Code

~50% of FPGA resources available for customization

Replace existing blocks with your own waveform designs

Fastest path from algorithm to prototype

Single language for host and FPGA design in LabVIEW

Documented for ease of use and understanding

Applications

- Customize LTE and 802.11
- LTE/802.11 coexistence
- New 5G waveforms
- Massive MIMO

mmWave Prototyping

NOKIA

“It took about 1 calendar year, less than half the time it would have taken with other tools”

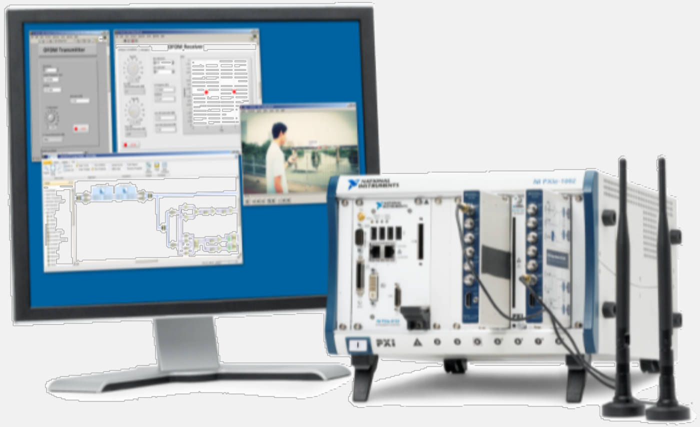
Dr. Amitava Ghosh, Head of Broadband Wireless Innovation, Nokia Networks

Nokia Timeline w/ NI Platform

NOKIA

	Brooklyn 5G Summit 2014	NIWeek 2015	MWC 2016
Frequency	73 GHz	73 GHz	73 GHz
Bandwidth	1 GHz	2 GHz	2 GHz
Streams	1x1	2x2	2x2
Modulation	16 QAM	16 QAM	64 QAM
Peak rate	**2.3 Gbps**	**>10 Gbps**	**>14.5 Gbps**

End-to-end Real-time LTE-like Wireless HD Video Link



- Prototype completed in 4 weeks
- MPEG-4 720p video streaming and playback over UDP at 1.5 Mbps
- 7.68MS/s IQ Rate, modeled after LTE framing
- Tx/Rx physical layer in LabVIEW FPGA with FlexRIO and 5791 RF Transceiver
- DSP prototyping in LABVIEW DSP Design Module with high-performance IP development in LabVIEW FPGA IP Builder

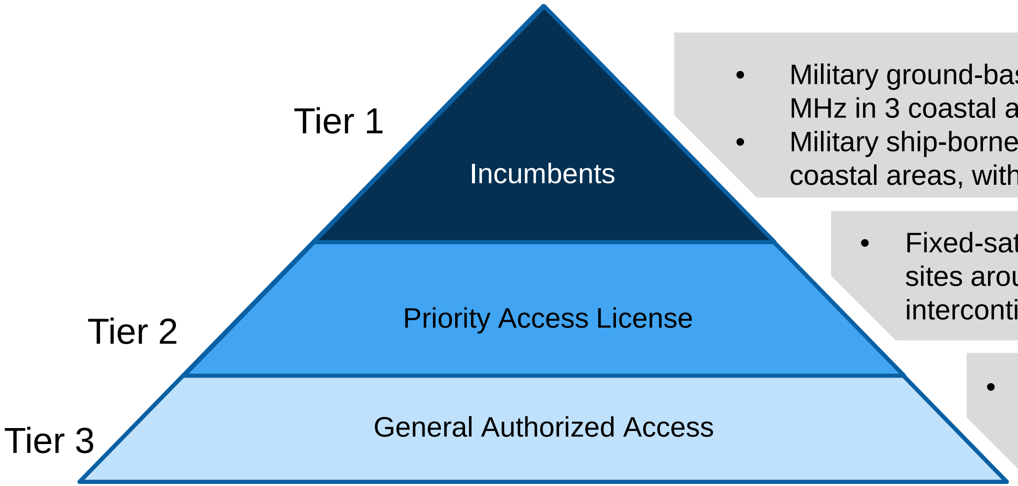
RUTGERS

"Impressive productivity in a very short amount of time"

Predrag Spanovic, Rutgers

Citizens Broadband Radio Service (CBRS)

- April 2015: FCC (US) adopted three-tiered spectrum sharing architecture for the “fast-track” band at (3550-3700 MHz)
- According to sharing rules, Tier 2 and Tier 3 devices can only use spectrum when it is ”clear”
- Environmental Sensing Capability (ESC) monitors spectrum and communicates with a central Spectrum Access System (SAS) which manages interference protection



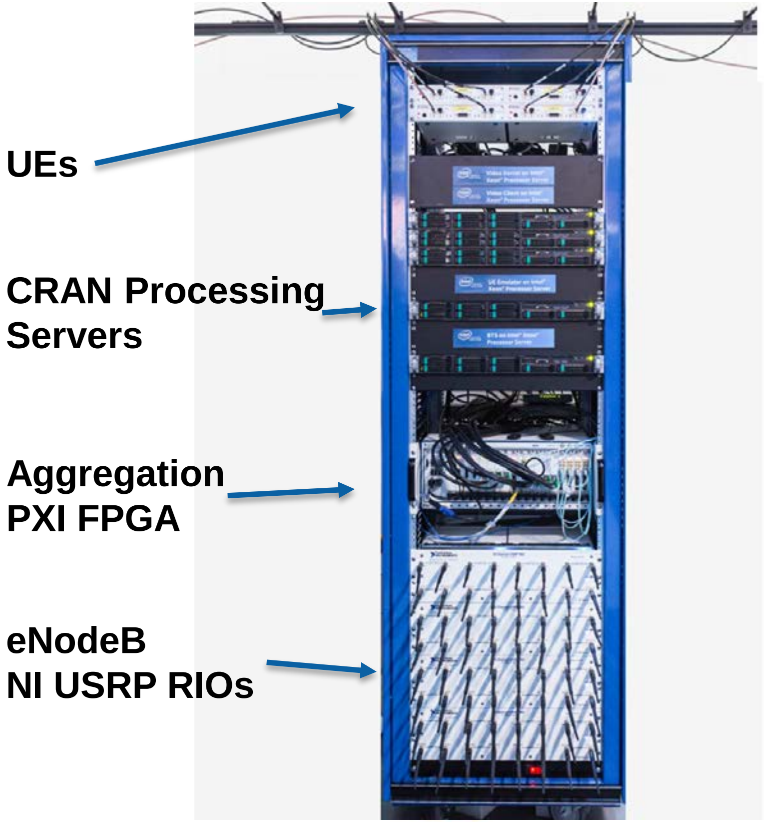
- Military ground-based radar: Occasional use at 3650-3700 MHz in 3 coastal areas
- Military ship-borne radar: Operate in 3550-3650 MHz in coastal areas, with 75% of traffic in 4 port cities

- Fixed-satellite service earth stations (receive-only): 35 sites around the U.S.; mostly coastal sites, limited to intercontinental international satellites

- Wireless Broadband Services (3650-3700 MHz: Thousands of small-cells that could be transitioned to Tier 2 or 3 operation after 5 years

Intel CRAN-Massive MIMO at MWC 2016

- 3.5GHz
- 64 antennas
- 5 UEs
- 20 MHz real-time bandwidth
- Full uplink and downlink – TDD
- Processing split between Intel Xeon servers and NI FPGAs



Bristol University Achieves 1.5 Gbps in 20 MHz

- 3.5GHz, 128 antenna system
- 10 UEs
- > 1.5 Gbps in 20 MHz spectrum
- MMSE, precoding in FPGA
- Pilot optimization
- LabVIEW, NI USRP RIOs

Prof Mark Beach

Paul Harris

University of BRISTOL

NATIONAL INSTRUMENTS

Cognitive Radio and Whitespace Detection

Dr. Paulo Marques & Dr. Gerhard Fettweis

LabVIEW Graphical System Design

- Spectral sensing with blind detection
- GPS geographic localization
- Adaptive spectrum utilization

COGEU

"LabVIEW software and the NI USRP hardware are key components of this research project, allowing the team to rapidly prototype and successfully deploy the first cognitive radio test bed of this kind"

Dr. Paulo Marques

instituto de telecomunicações

NATIONAL INSTRUMENTS

High-Resolution Software Defined Radar System for Target Detection

Flexible Radar Prototyping

- Rapidly switch between synthetic-aperture radar (SAR), Radar Meteo, Doppler, etc.
- Easy implementation of new radar signal processing algorithms.
- Low overall system cost with wide frequency coverage

Sandra Costanzo, Università della Calabria

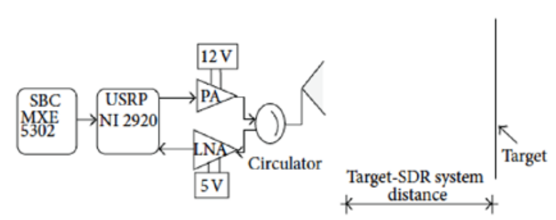


Figure 10: Scheme of indoor test setup.

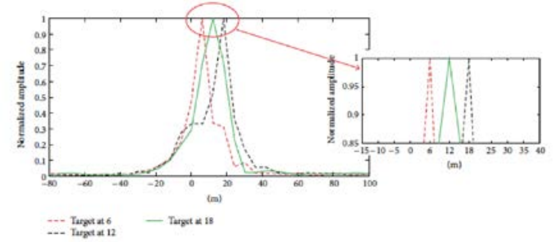


Figure 8: Retrieved signal peaks for different target positions.

Passive RADAR Design on PXI

- Digital beam forming to determine the direction of arrival of signals
- Adaptive filtering to cancel any unwanted direct signal returns
- Cross-correlation of the reference channel with the surveillance channels

SELEX Sistemi Integrati

"We chose NI products is because of the user-friendly environment to develop the software"

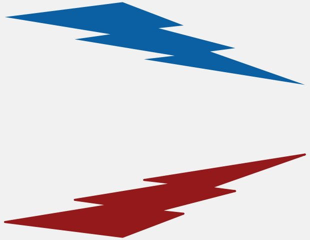
Dr. Riccardo Mancinelli,
Selex Sistemi Integrati

RF - DNA Fingerprinting Prototype System

Device identification based upon unique characteristics of EM/RF emissions

Authorized User 1

Intruder posing as Authorized User 1

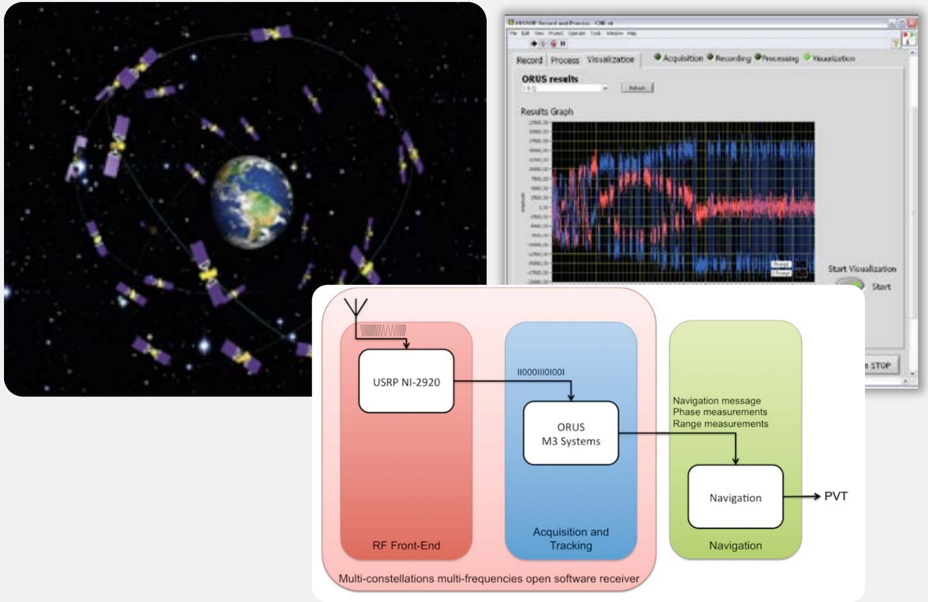


- Both nodes transmit identical signals
- The intruder attempts to access the network by assuming the identity of Authorized User 1

Access Point enabled with RF-DNA Fingerprinting

- Using RF-DNA fingerprinting, the AP can discern the differences in RF signature of the two identical signals
- Authorized User 1 is granted access while the intruder is blocked and marked for location

Developing an Open Multiconstellation GNSS Receiver



Multiconstellation Position Tracking

- Track multiple global navigation satellite constellations concurrently, recording, processing, and visualizing the results
- Acquisition performed by ORUS (open software receiver developed by M3)
- Current coverage for both GPS (United States) and Galileo (Europe) constellations

Olivier Desenfans, M3 Systems

SDR Integrators Ecosystem

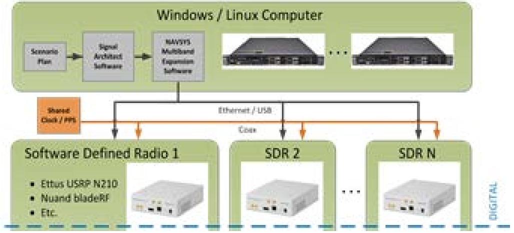
Commercial LTE basestation

NAVIGATION LABORATORIES
Leaders in GPS Simulators

GPS Simulators using FPGAs

SCA Compliant SDR systems

X-series USRP for GPS record, playback and simulation.



GPS Simulators

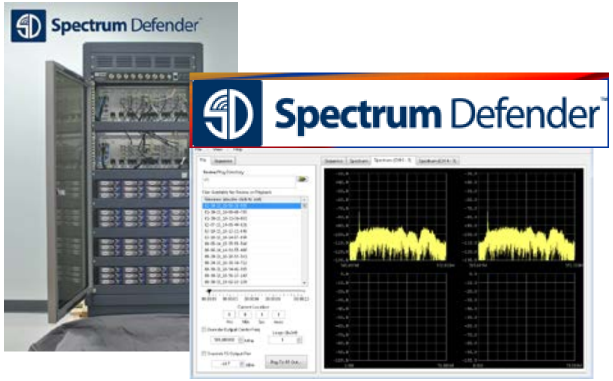
RedHawk: An ecosystem for mil/gov SDR applications

PXI Integrators Ecosystem

Decodio

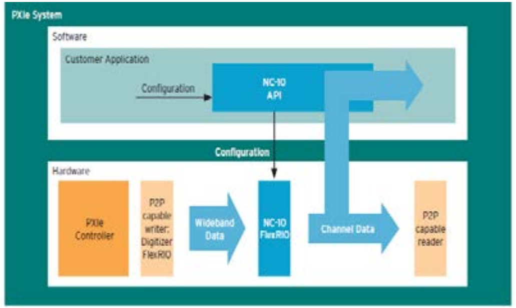
- COMINT for critical communications
- Arbitrary narrow—band
- Channels
- High Throughput
- Fast Scanning and Triggering

Acquired Data Solutions Inc



- 2D Geo-Location
- 8-channel Spectrum Environment Emulation
- Post-capture analysis
- Cross-Platform integration

NOVATOR SOLUTIONS



- NC10 Channelizer
- Continuous Sample Mode
- Configurable Channels
- Programmability

NATIONAL INSTRUMENTS

COTS Platform-Based Design For Spectrum Monitoring & Signal Intelligence

Dr. James Truchard

President, CEO, and Cofounder
National Instruments