Configuring a Phase-Coherent RF Record and Playback System

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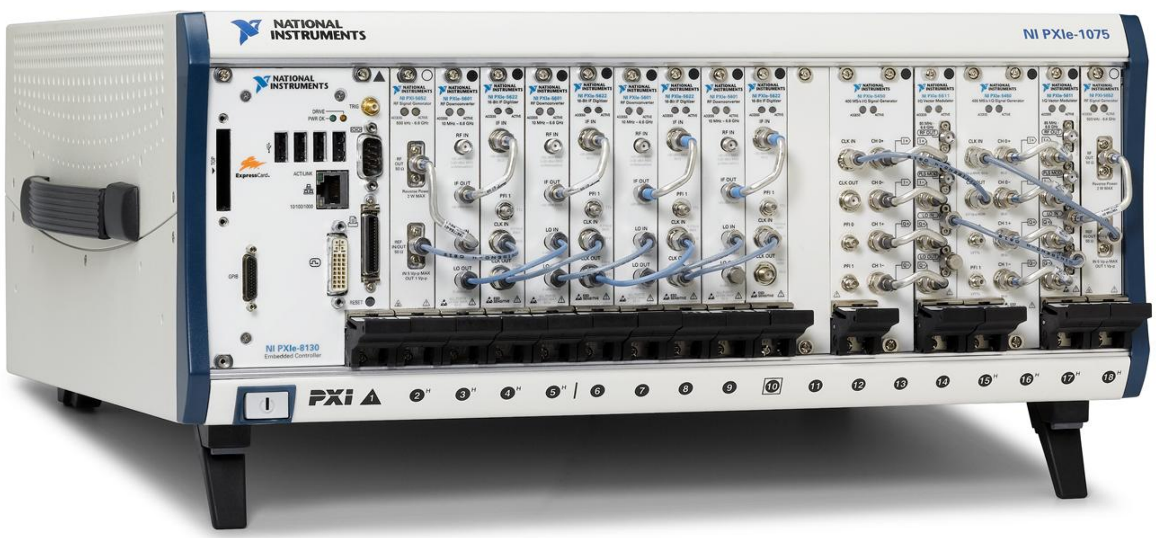


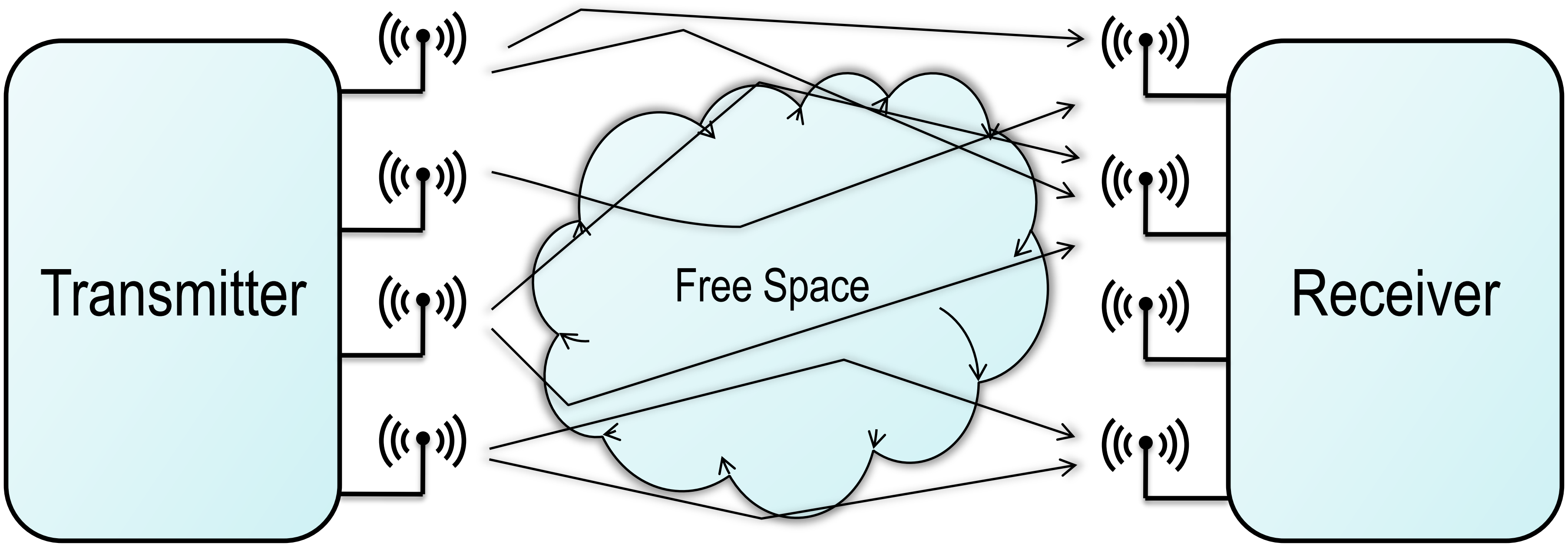
Agenda

- Applications that require multiple RF channels
- Step 1: Synchronizing RF channels
  - Achieving multichannel phase coherency
  - Typical synchronization results
- Step 2: Configuring an RF record and playback system
  - Why record and play back?
  - Challenges in off-the-air recording systems
  - Typical system configuration
- Example systems

Multichannel RF Applications

MIMO – Multiple Input, Multiple Output

- Common configurations are 2x2 and 4x4
- Used in 802.11n, WiMAX, LTE, and evolving standards
- Use of spatial domain yields higher data throughput



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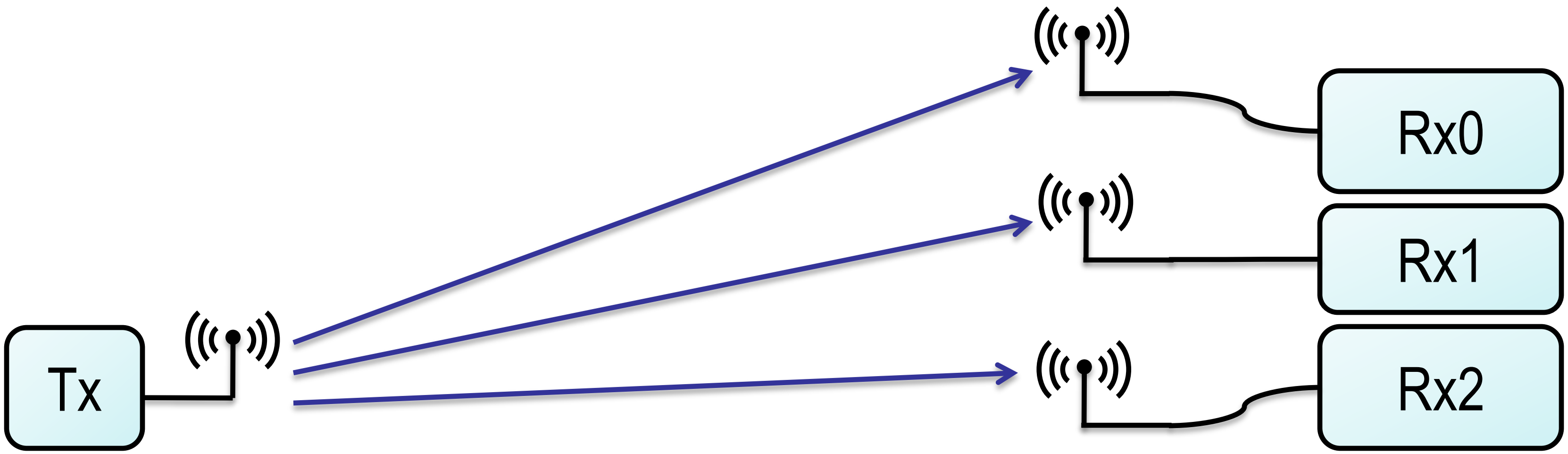
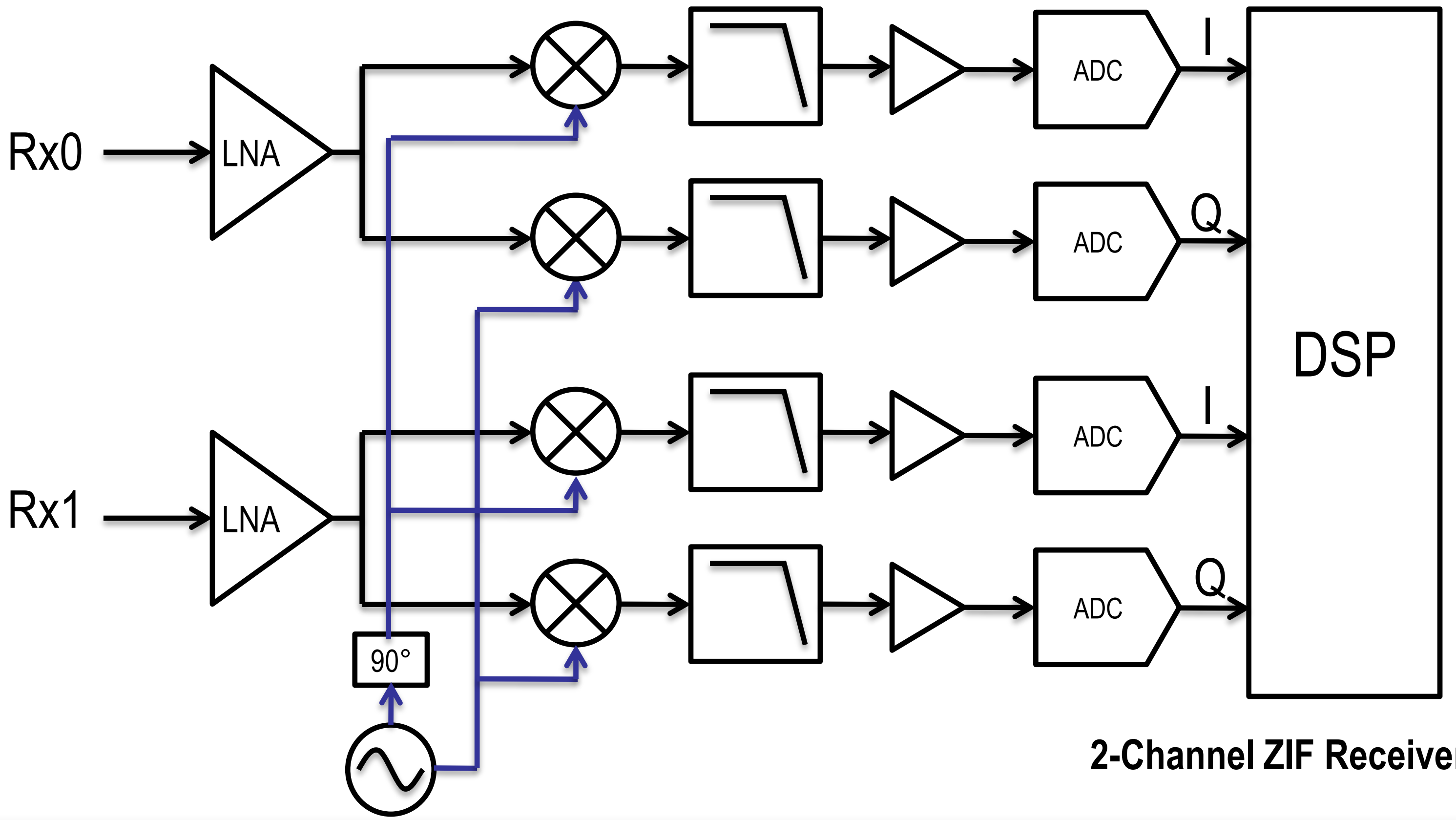
Direction Finding

- Three or more receive antennas
- Unique propagation delay to each receiver
- Direction can be calculated through phase difference



Antenna Diversity Receivers

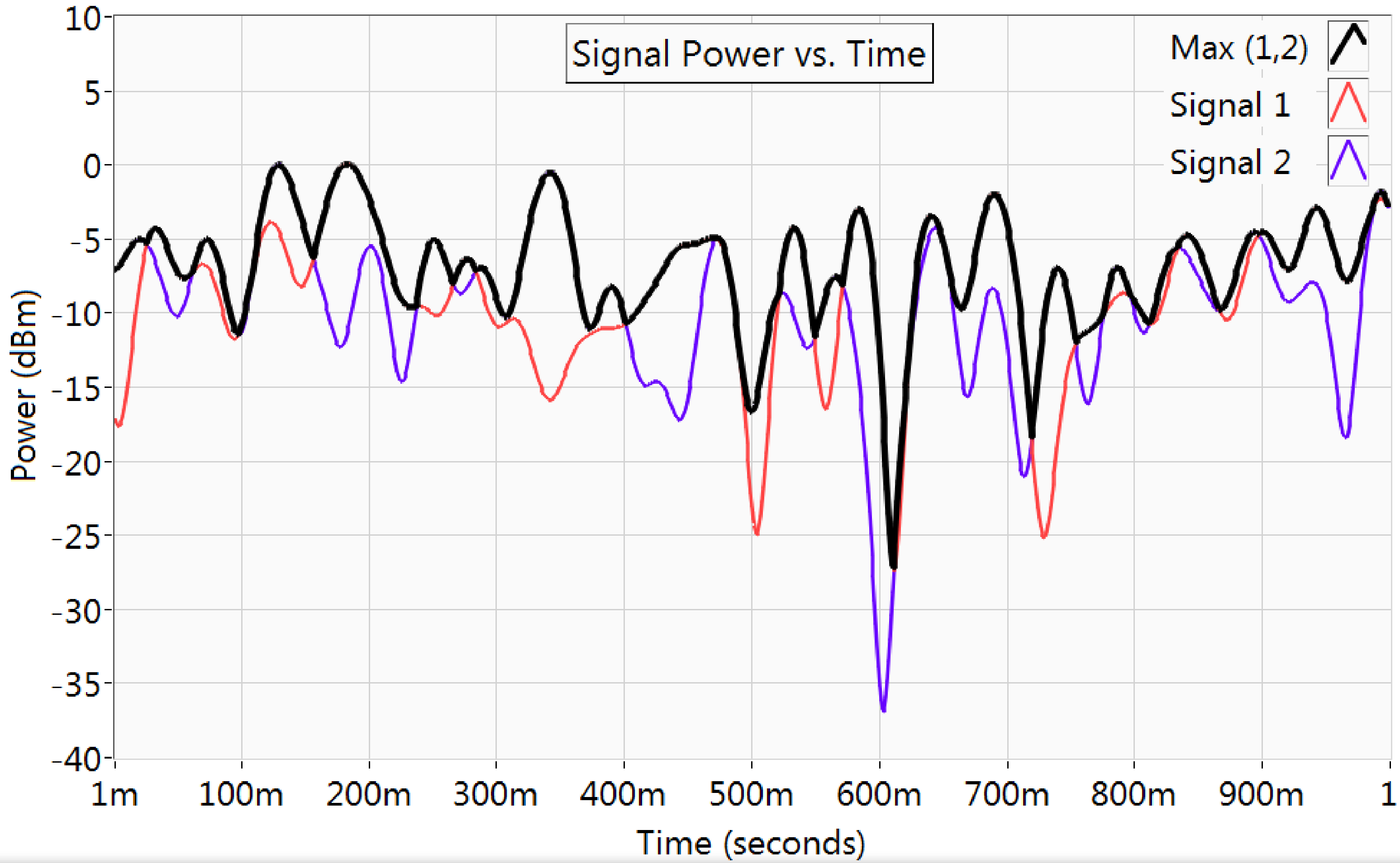
- Each channel is completely synchronized
- Synchronization requires sharing of LO and sample clocks



2-Channel ZIF Receiver

Diversity and Signal Power

- Diversity increases receive signal strength

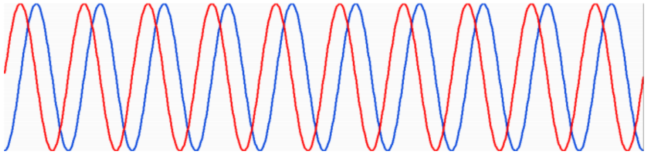


Step 1: RF Synchronization

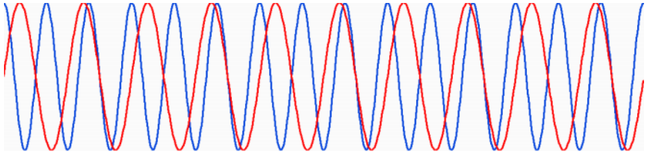
Phase Coherency Definition

- The attribute of two or more waves, or parts of a wave, where relative phase is constant during the resolving time of the observer

- Usually implies a frequency lock between signals of the same frequency
  - Different frequencies mean constantly changing relative phase

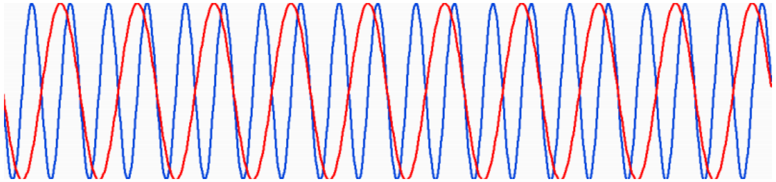


versus



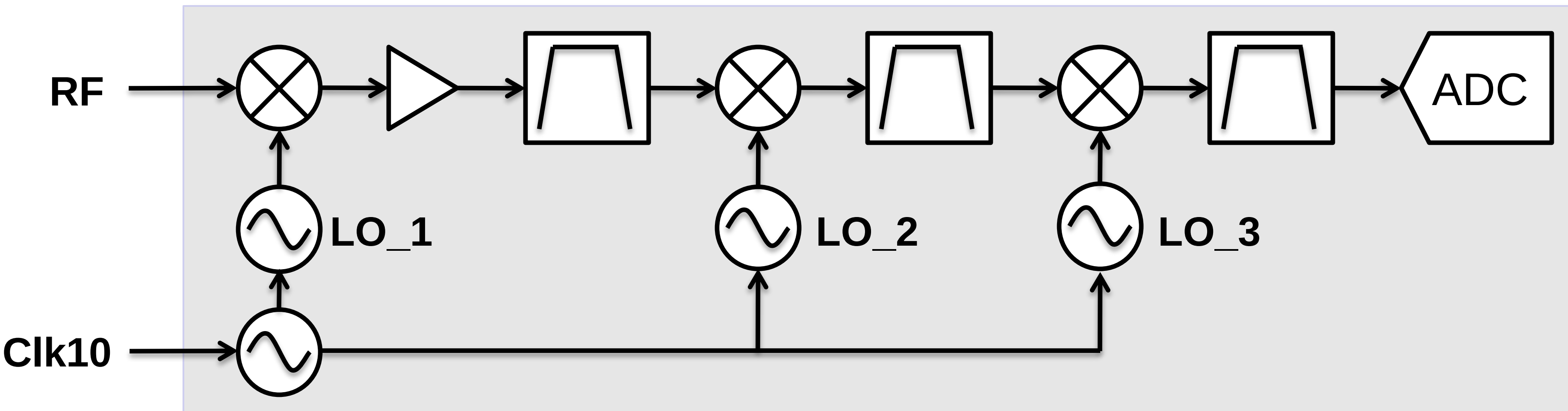
Same Frequency **Different Frequencies**

- Can also be interpreted for signals of different frequencies
  - Signals are at a specified phase relationship every N cycles



Traditional VSA Architecture

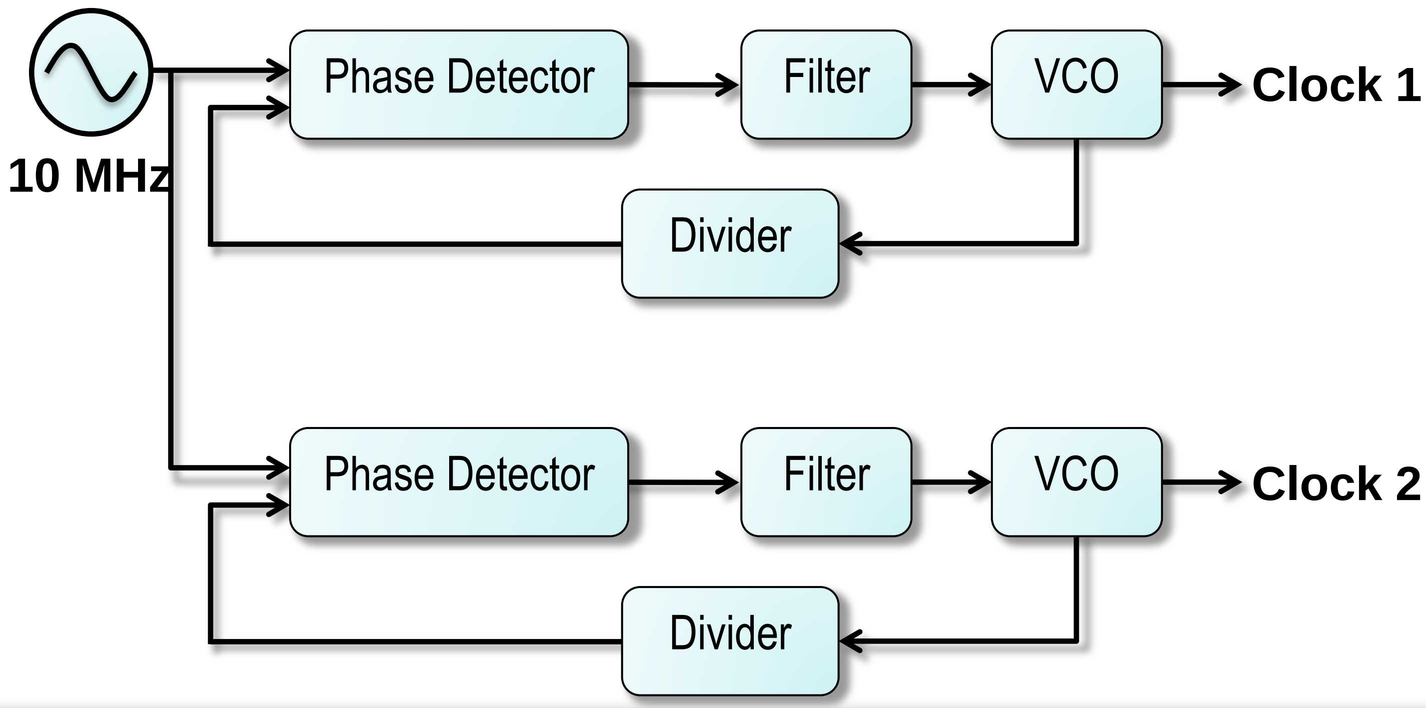
- Traditional VSAs use 3-stage superheterodyne architecture
- Can share 10 MHz reference – not the local oscillators (LO_1, etc.)



NI PXI-5661

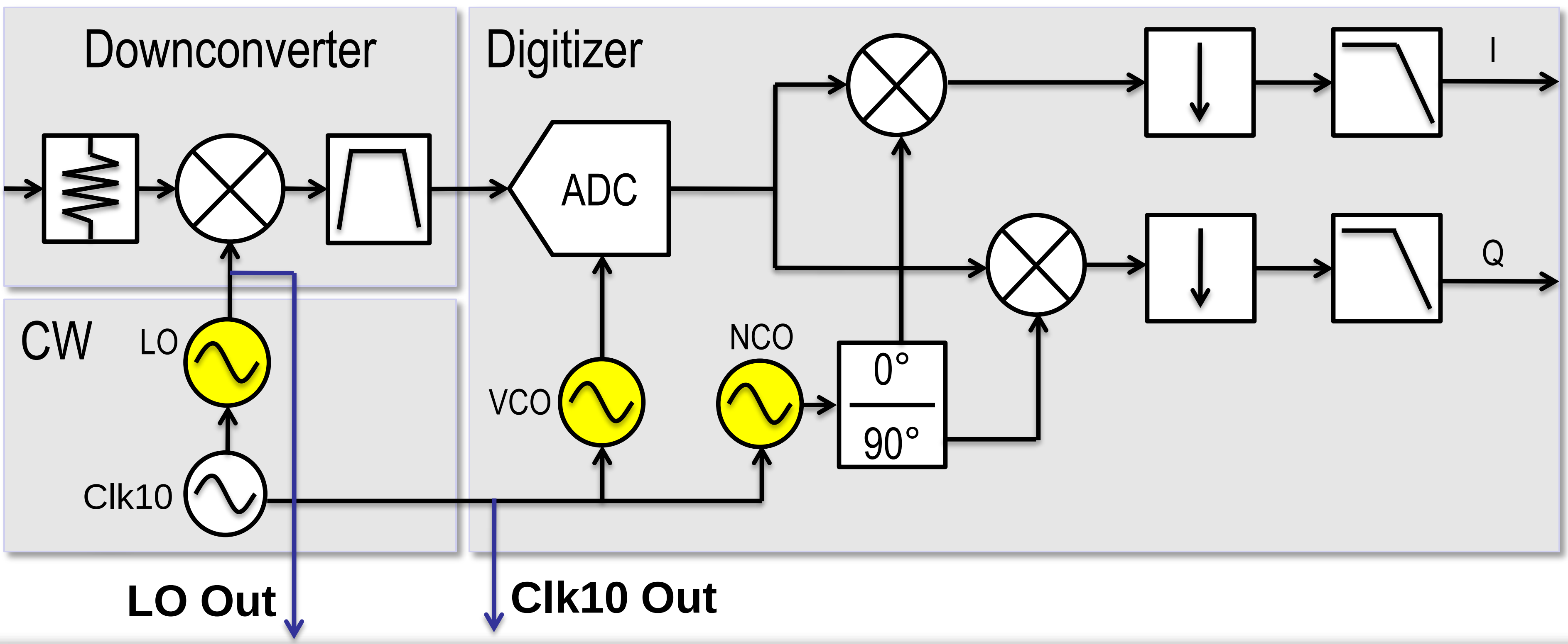
Shared Reference Clock

- Sharing a reference clock introduces PLLs on individual channels
  - Each PLL has its own unique phase-noise contribution
  - Divider states can introduce uncertainty in mean output phase deltas



Synchronizing a Single-Stage VSA

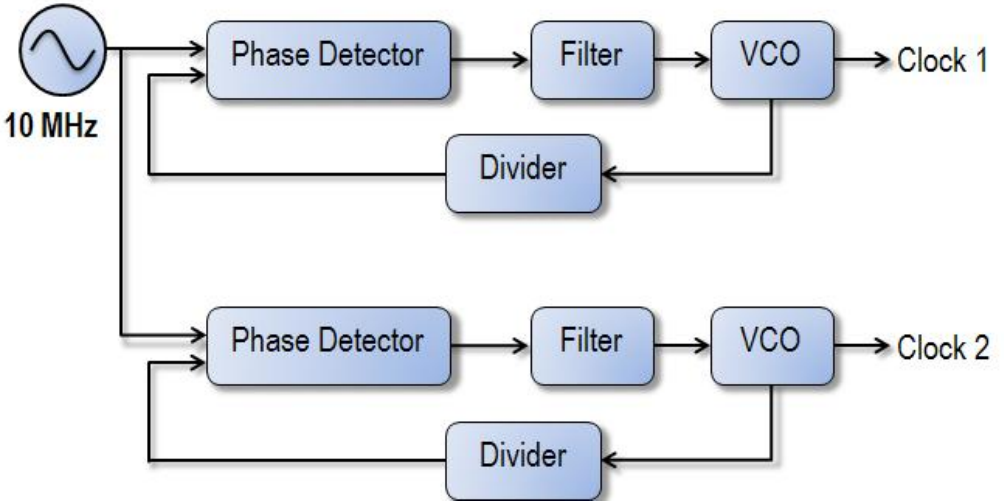
- Shared clocks include:
  - Local oscillator (LO derived from VCO)
  - ADC sample clock and DDC numerically controlled oscillator (NCO)



LO Clock Sharing Comparison

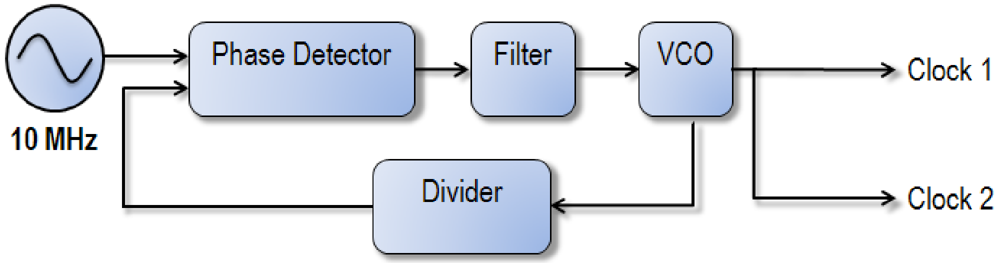
Shared Reference Clocks

- PLL count expands with channel count
- Each channel has uncorrelated phase noise
- PLL divider adds to uncertainty

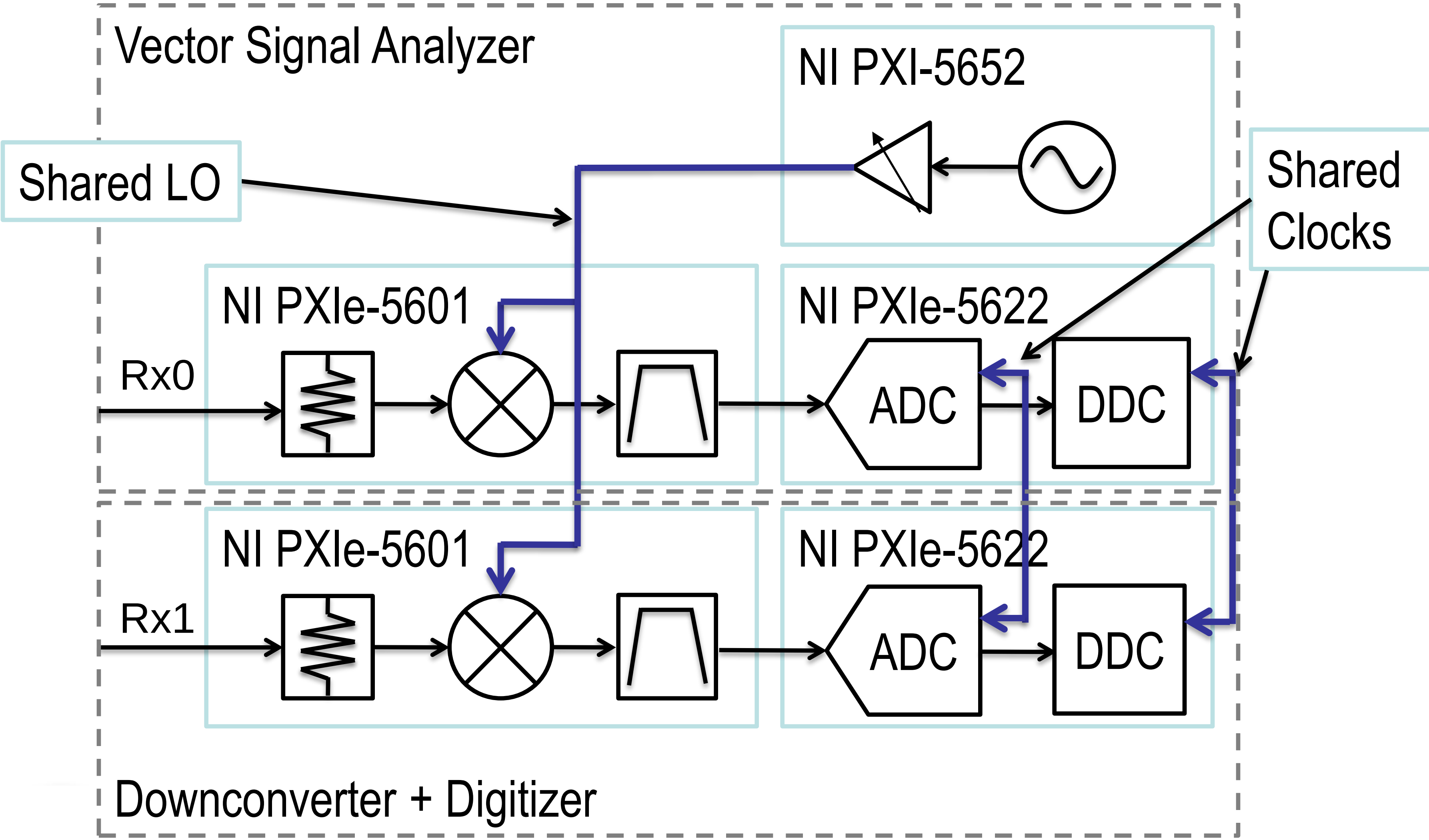


Shared LO and Sample Clocks

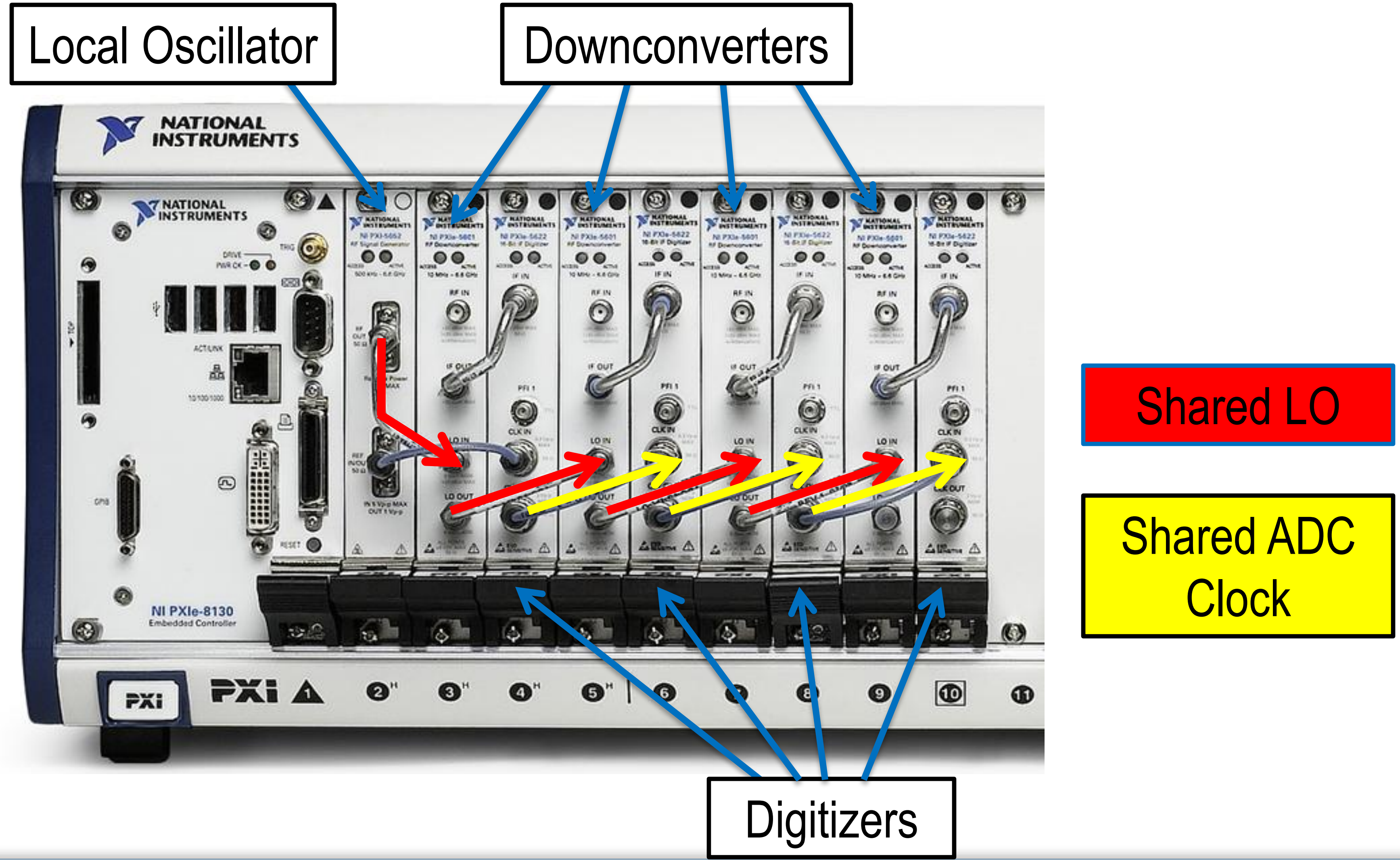
- One PLL per clock (master)
- Uncertainty from PLL phase noise and dividers correlated, cancels out
- **PREFERRED METHOD**



Phase Coherent x2 RF Acquisition



Four-Channel Phase-Coherent Acquisition

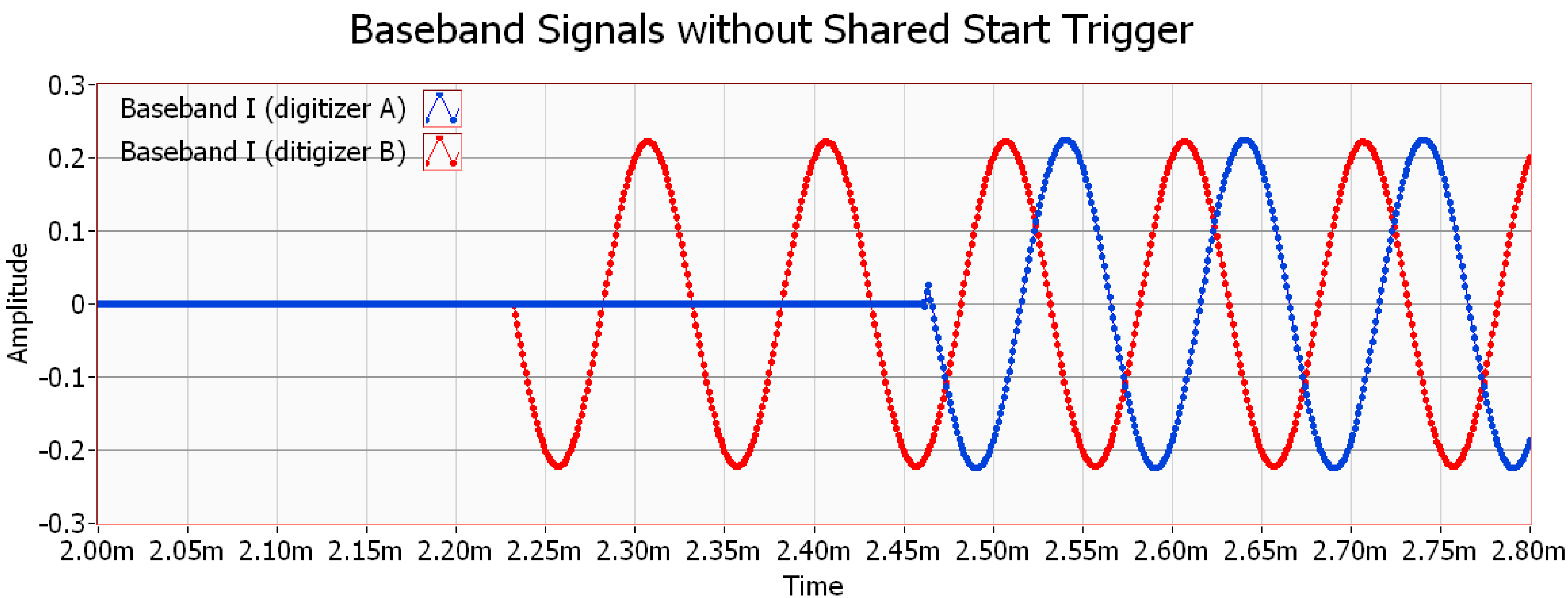


Other Synchronization Concerns

- Shared clocks
  - Local oscillator (LO)
  - ADC sample clock
  - DDC numerically controlled oscillator (NCO)
- Other synchronization concerns
  - Shared versus independent start trigger
  - Calibrated versus uncalibrated phase

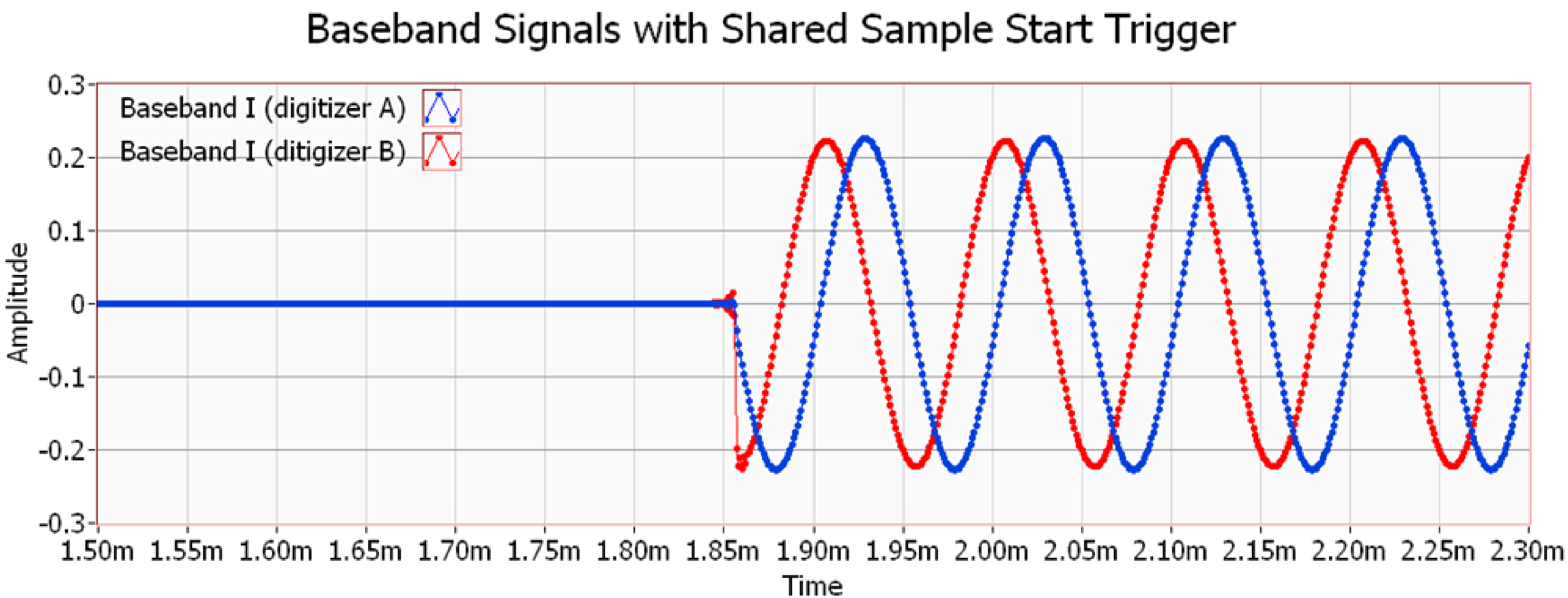
Channels Not Synchronized or Aligned

- Channels are phase coherent but …
- Time (trigger) and phase offset still present
  - Synchronized trigger and phase alignment needed



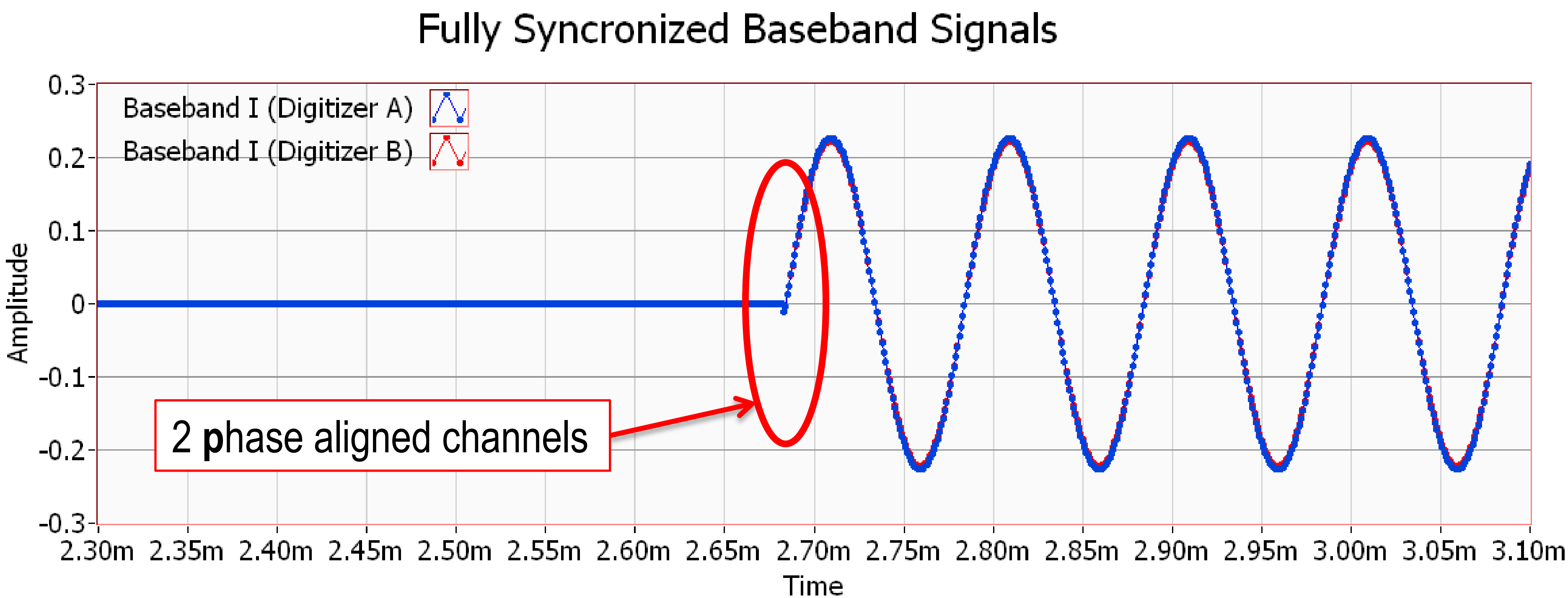
Synchronized and Not Calibrated

- Analyzers maintain constant carrier phase relationship
- Discrete phase offset present at baseband
  - Requires NCO start-phase adjustment

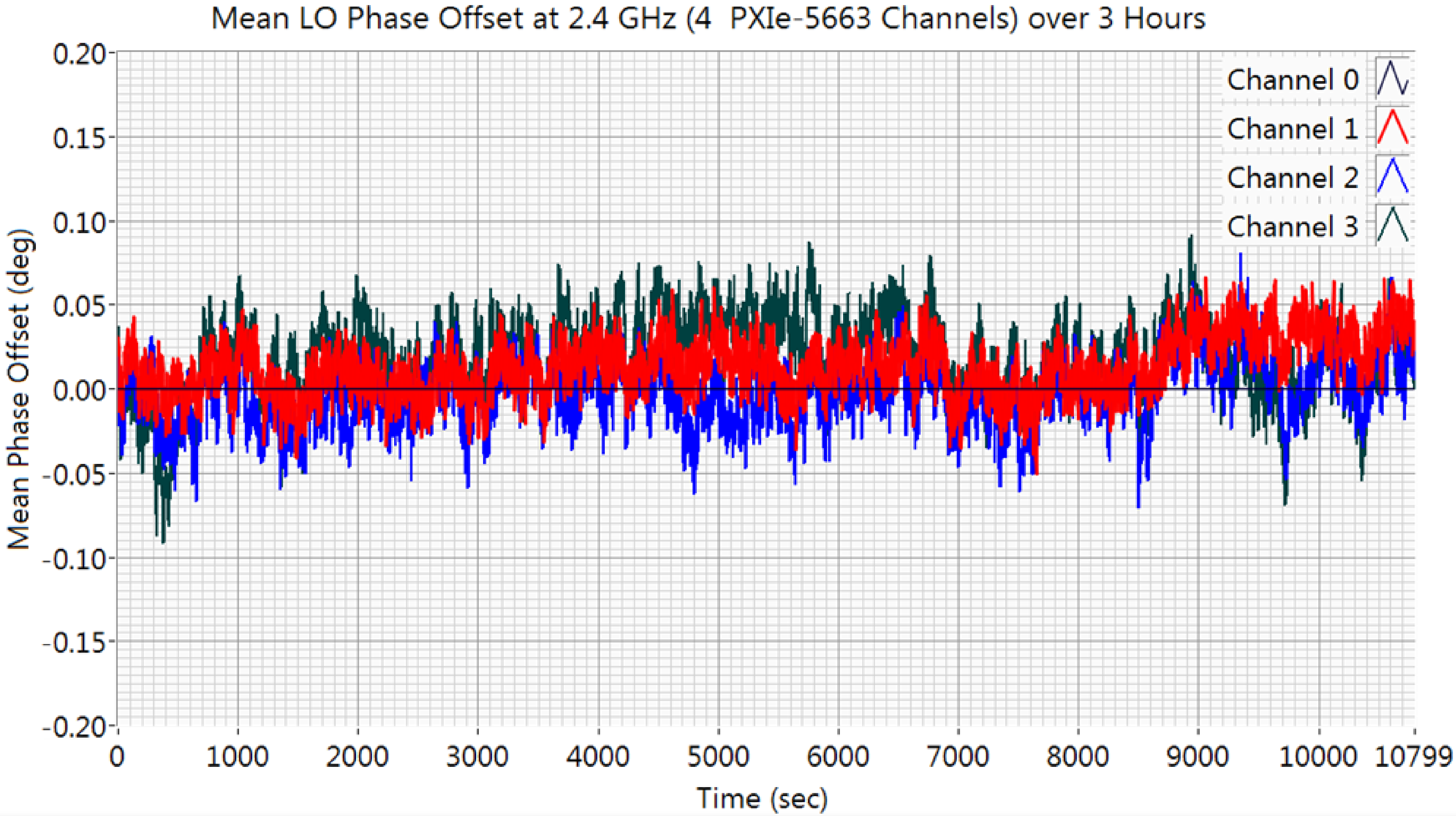


Channels Synchronized and Aligned

- Onboard signal processor (OSP) uses digital carrier called NCO
  - Can be manually adjusted per channel (VSA and VSG)
  - Compensates for channel-to-channel phase offset
  - 0.0055 degree phase adjust resolution

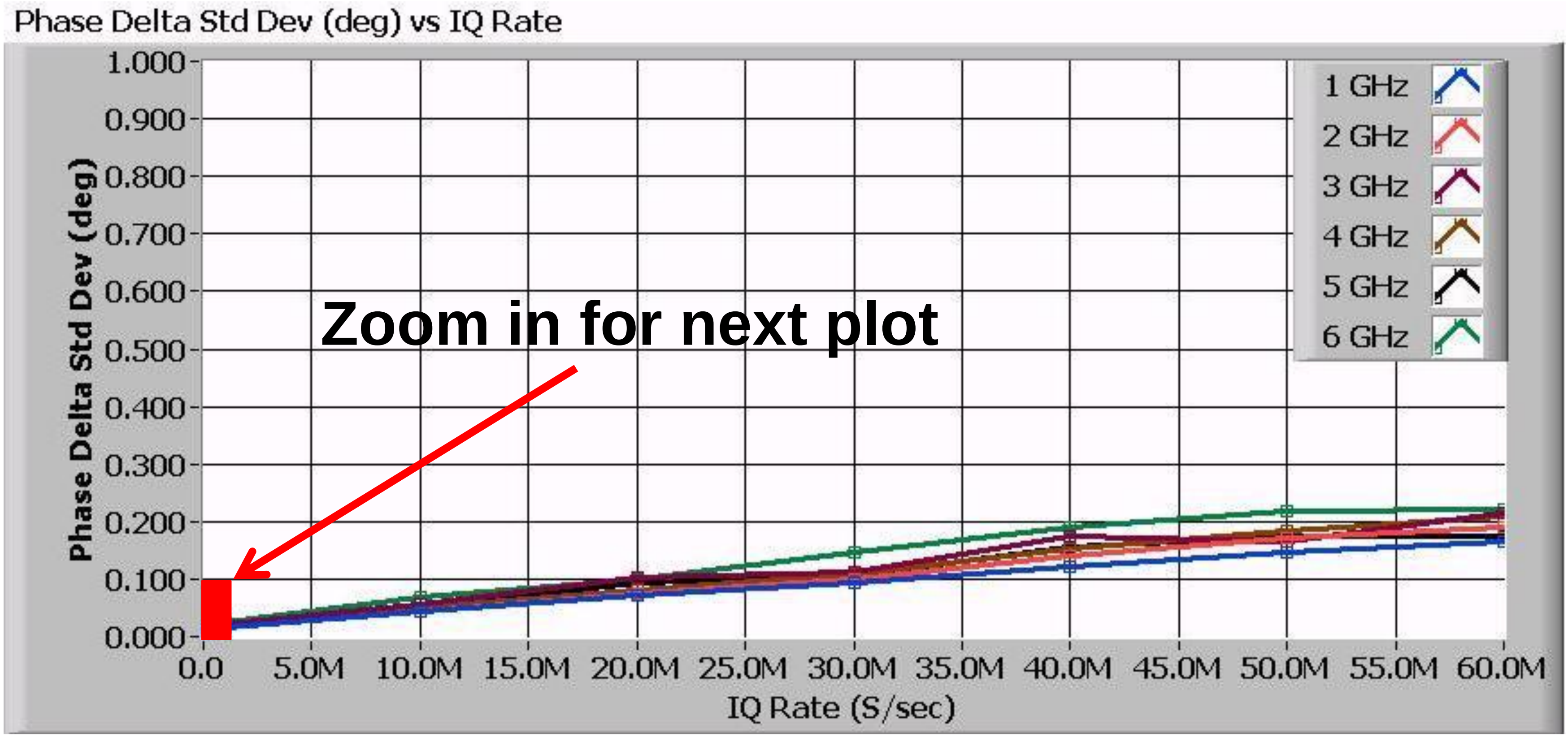


VSA Synchronization Stability



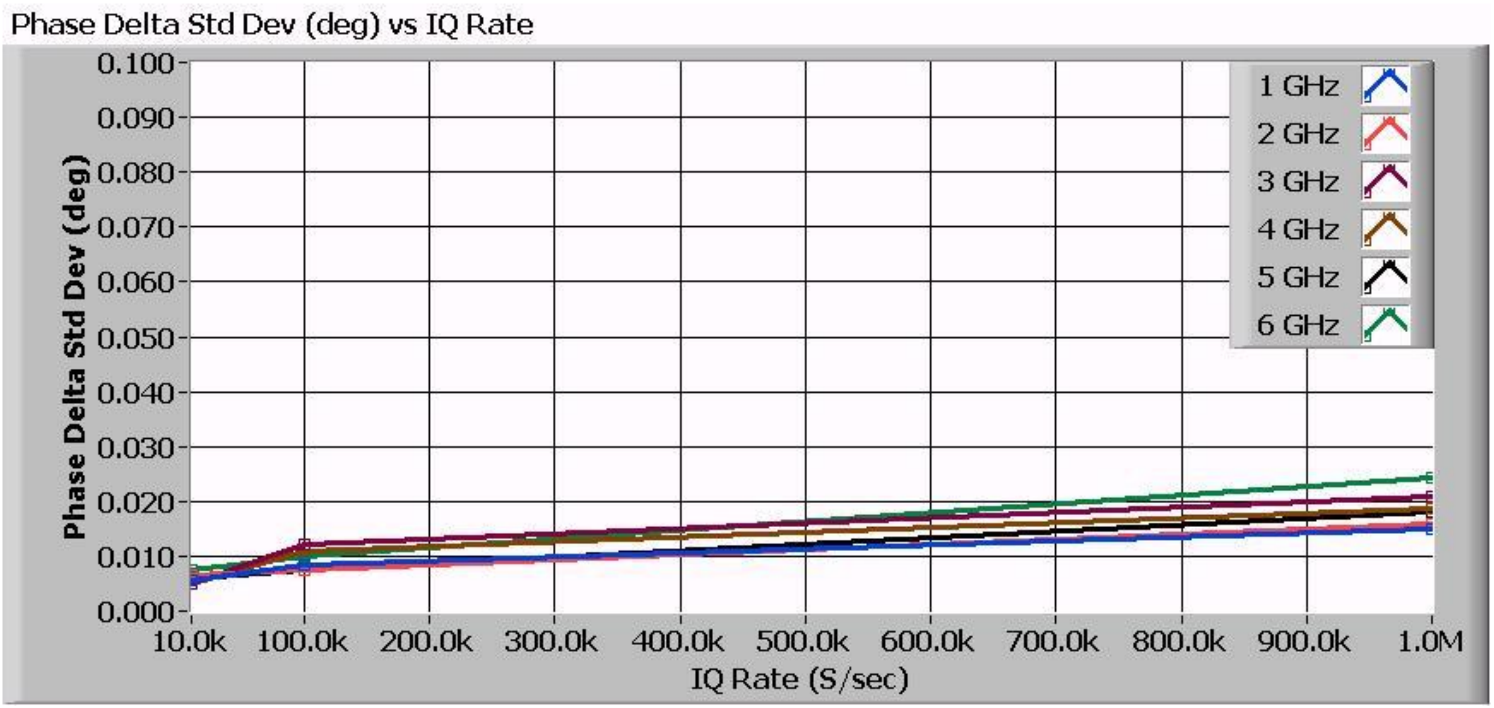
Phase-Coherency Performance Plots – VSAs

- Full scale input to two NI PXIe-5663 VSAs (0 dBm CW, 0 dBm ref level)
- **Increasing IQ rate reduces SNR (noise floor increases)**



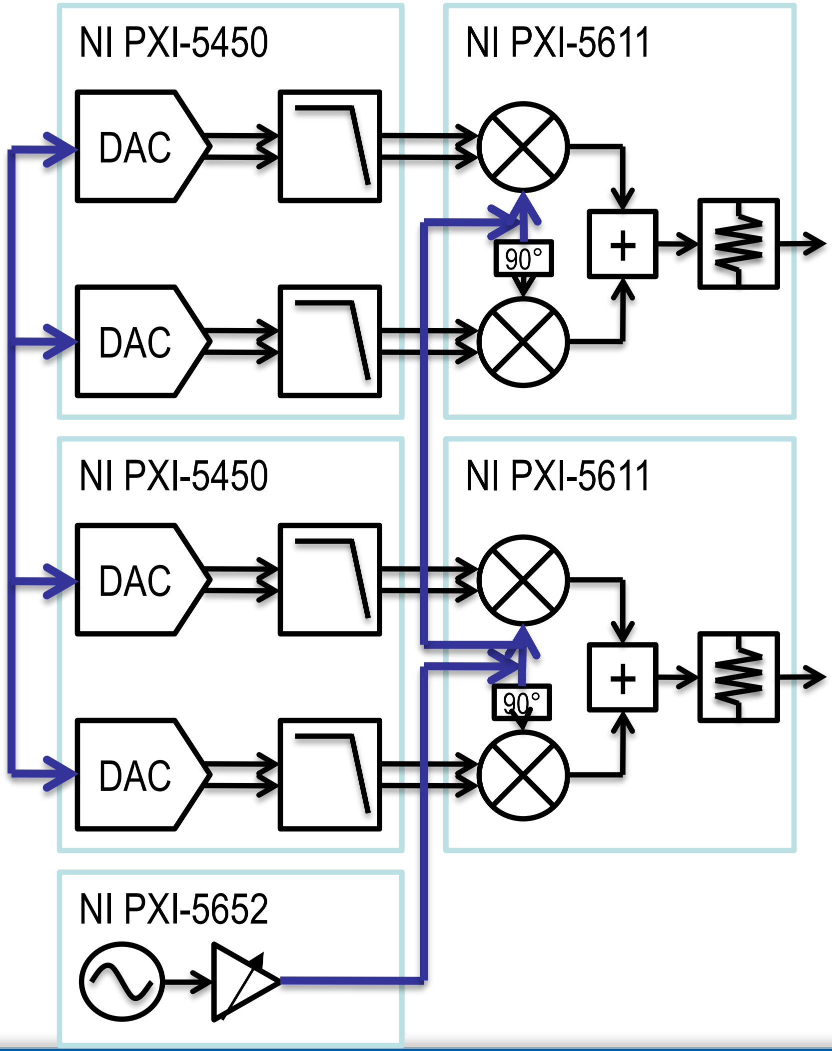
Phase-Coherency Performance Plots – VSAs

- Full scale input to two NI PXIe-5663 VSAs (0 dBm CW, 0 dBm ref level)
- **Plot below zooms in relative to prior plot (IQ Rates ≤ 1.0 MS/s)**
- Y scale max is now 0.1 degree (prior plot Y scale max is 1 degree)

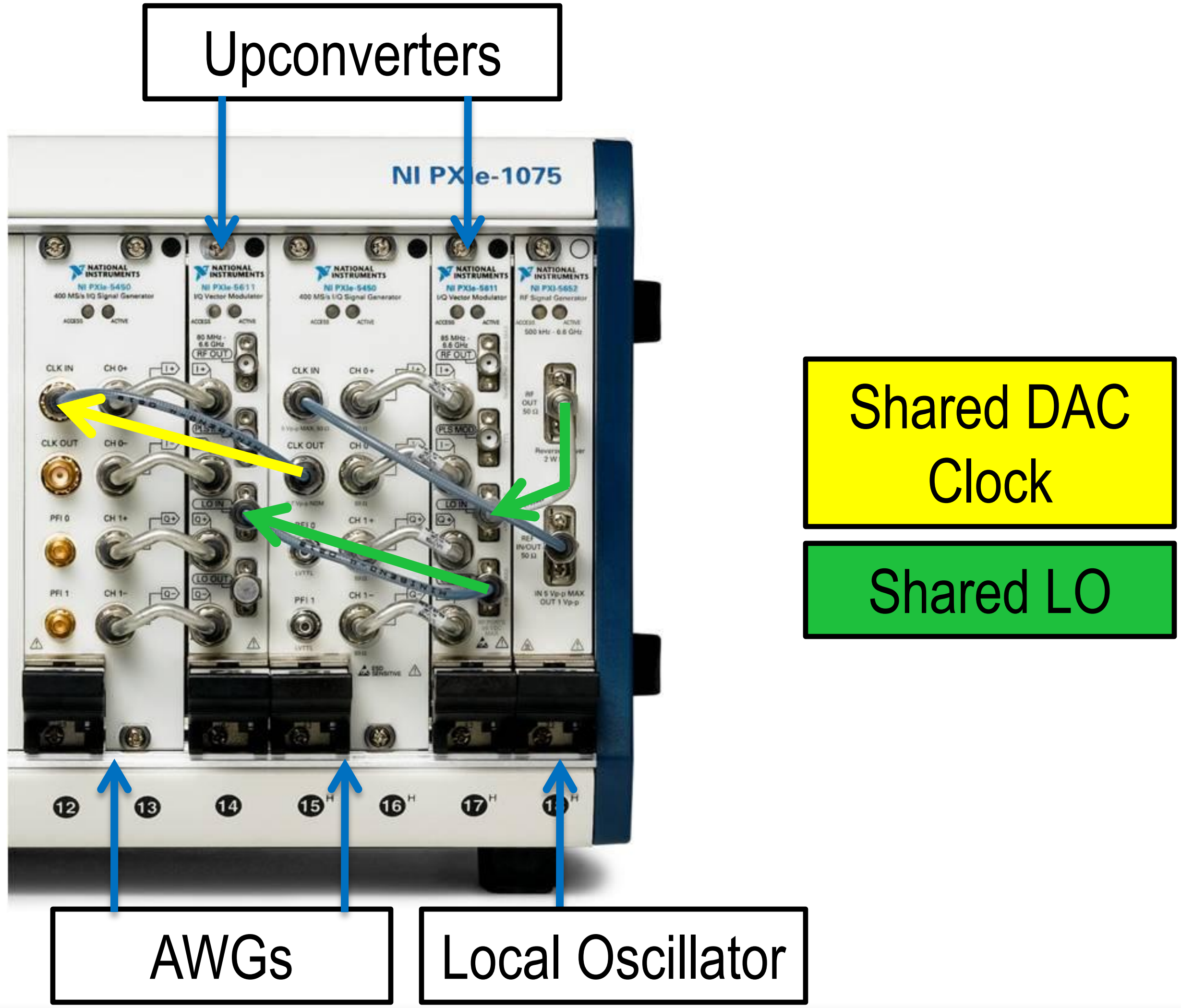


Synchronizing RF Signal Generators

- NI PXIe-5673 contains 3 modules
  - NI PXIe-5450 AWG
  - NI PXIe-5611 RF upconverter
  - NI PXIe-5652 CW Sources
- VSGs use direct RF upconversion
  - i.e. Quadrature modulation
- Shared clocks include:
  - Each AWG shares baseband sample clock and 10 MHz reference
  - Each modulator shares common LO
  - LO must be phase calibrated



Two-Channel Synchronized Generation



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Step 2: Record and Playback

Johan Olsson
National Instruments

4X2 PXI based MIMO configuration as an example for a streaming setup

RF Record and Playback

- Record and play back up to 2 TB of data with NI HDD8264
- Use for long-duration signals and GPS/DVB receiver testing

NI PXIe-5663 ***to disk***

- 50 MHz bandwidth (62.5 MS/s)
- 250 MB/s
- Record for 2.0+ hours
- May require preselection

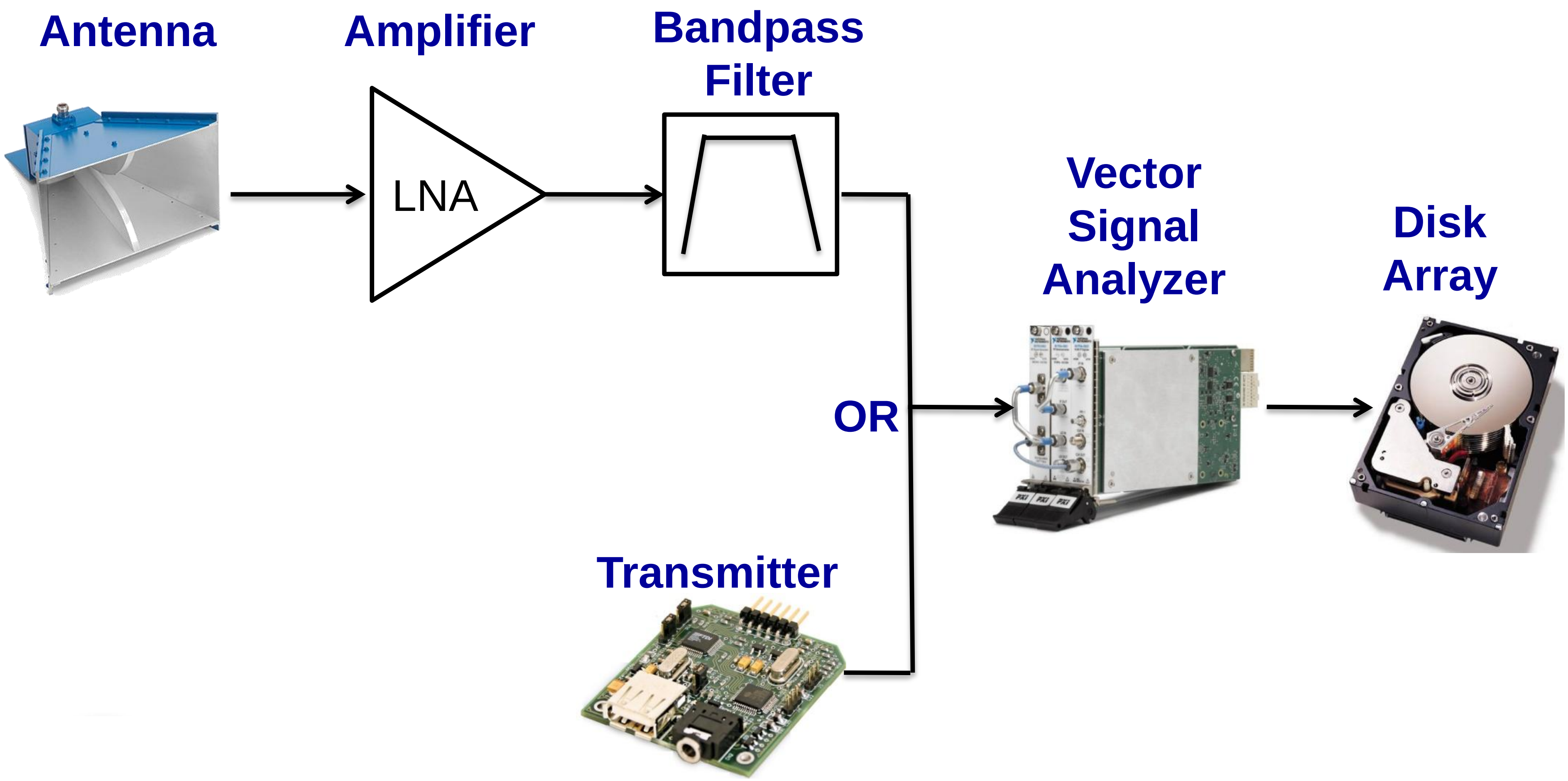
NI PXIe-5673 ***from disk***

- 100 MHz bandwidth (125 MS/s)
- 500 MB/s
- Playback for 1+ hours
- Large waveforms can also be created in software

Math Stuff: Signal Bandwidth to Duration

- RF bandwidth = 0.8 x I/Q rate
  - For example, 50 MS/s = **40 MHz** real-time bandwidth
  - Conversion artifact of digital downconversion
- Data rate = 4 bytes per sample x I/Q rate (samples/s)
  - Each sample = 2 bytes for I and 2 bytes for Q
  - 40 MHz = 50 MS/s x 4 = 200 MB/s
- Duration with 2 TB array
  - 50 MHz = 2 Hours
  - 40 MHz = 2.5 Hours
  - 20 MHz = 5 Hours
  - 4 MHz = 25 Hours

Overview of an RF Recording System



Key Recording Technologies

High-Speed Bus

PCI EXPRESS®

PXI

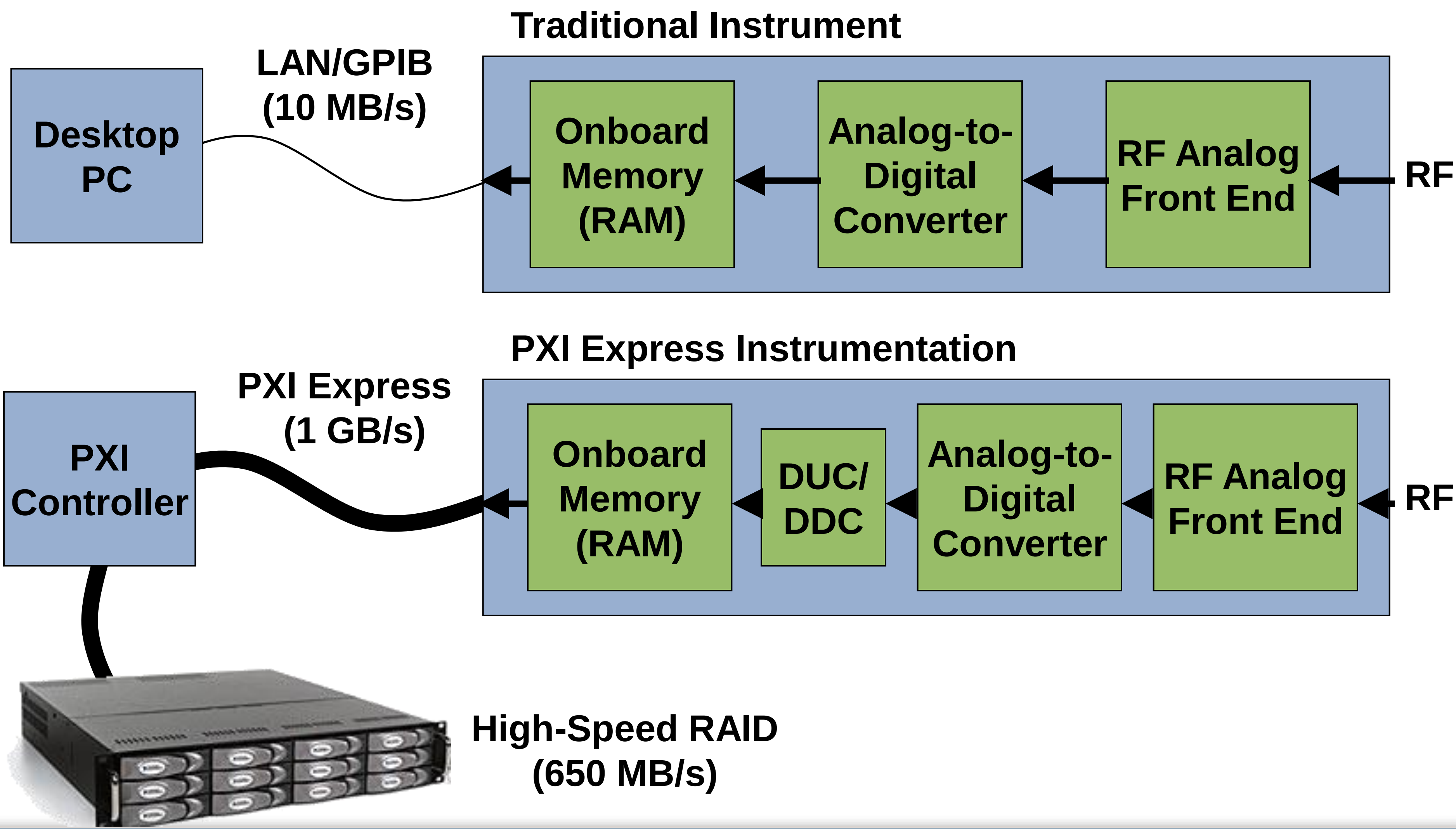
High-Speed Disk

NI LabVIEW Example Code

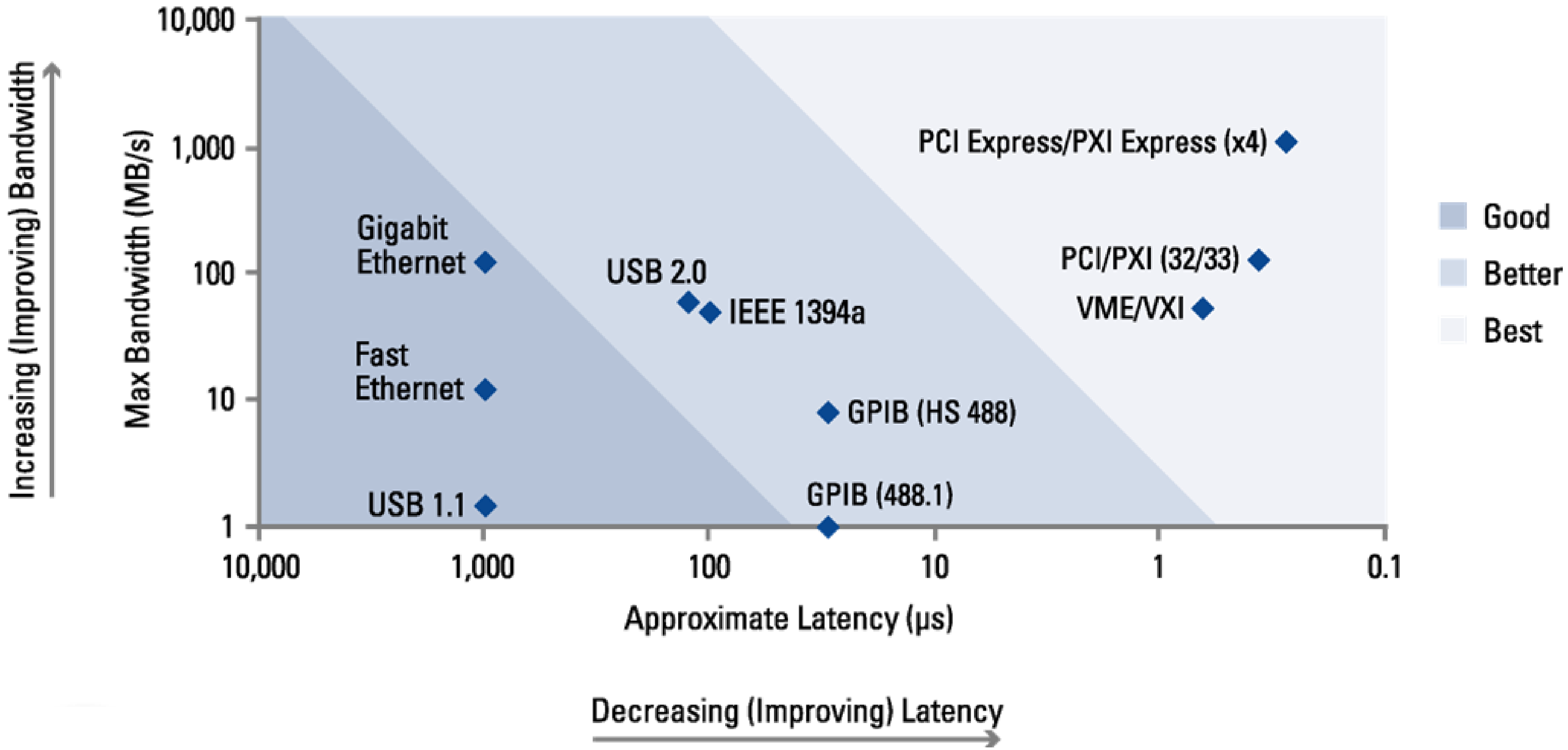
POWERED BY

NATIONAL INSTRUMENTS LabVIEW

Instrument Architecture – VSA



Technology 1: High-Speed Data Bus

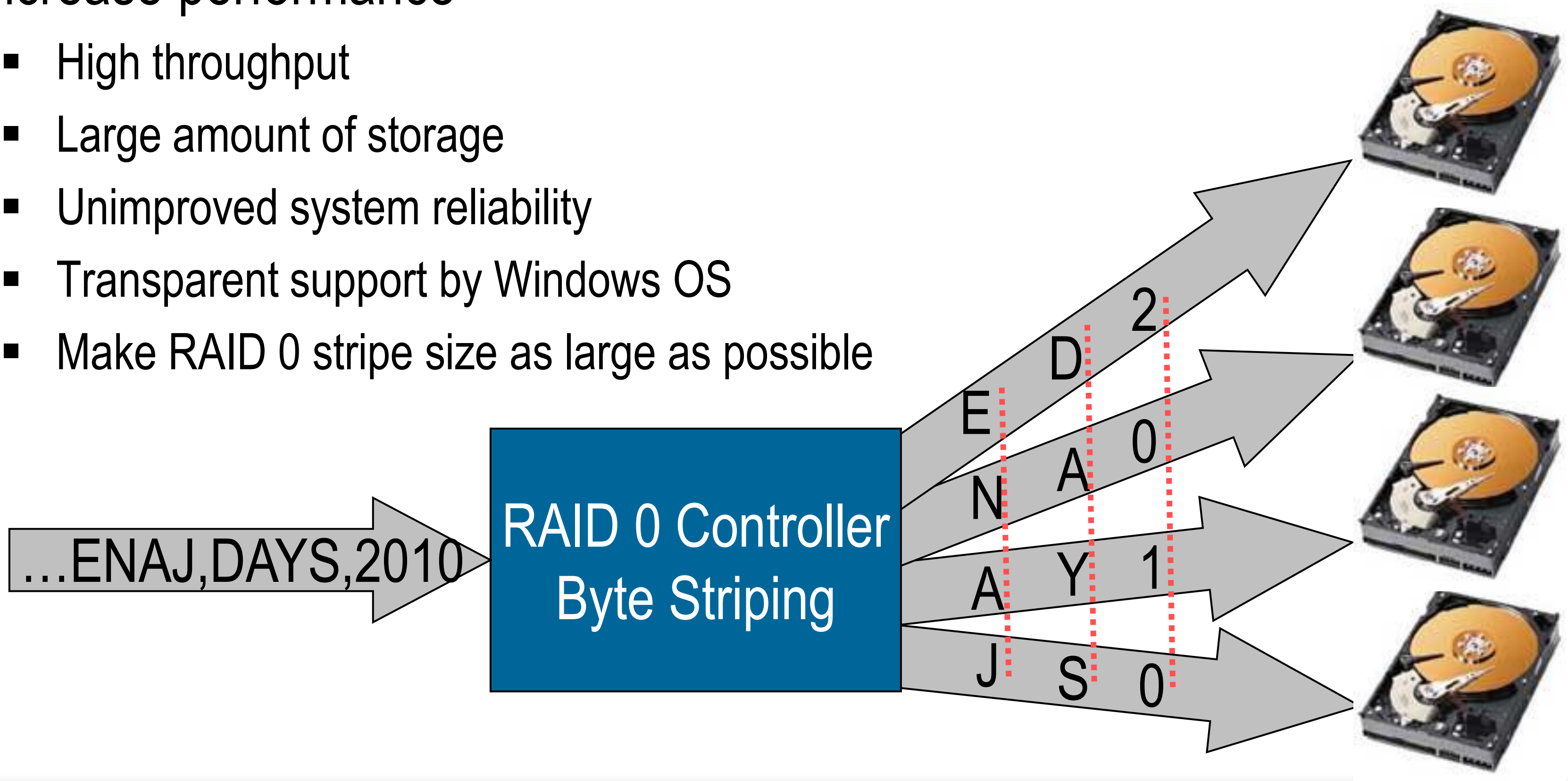


PCI\PXI Express to get the bandwith needed

- Serial interconnect at 2.5 Gbits/s
  - PCI transactions are packetized and then serialized
  - Low-voltage differential signaling, point-to-point
  - x1 (by 1) has bandwidth of 250 Mbytes/s/direction
  - x16 (by 16) has bandwidth of 4 Gbytes/s/direction
- Software compatibility with PCI
- 6 GB/s total system bandwidth
- Enhanced synchronization capabilities
- Hybrid slots support PXI and PXI Express modules in same slot
- Long life (20+ years in mainstream market)

Technology 2: RAID

- Redundant Array of Independent Disks
- With RAID 0, parallel operations on multiple hard drives increase performance
  - High throughput
  - Large amount of storage
  - Unimproved system reliability
  - Transparent support by Windows OS
  - Make RAID 0 stripe size as large as possible



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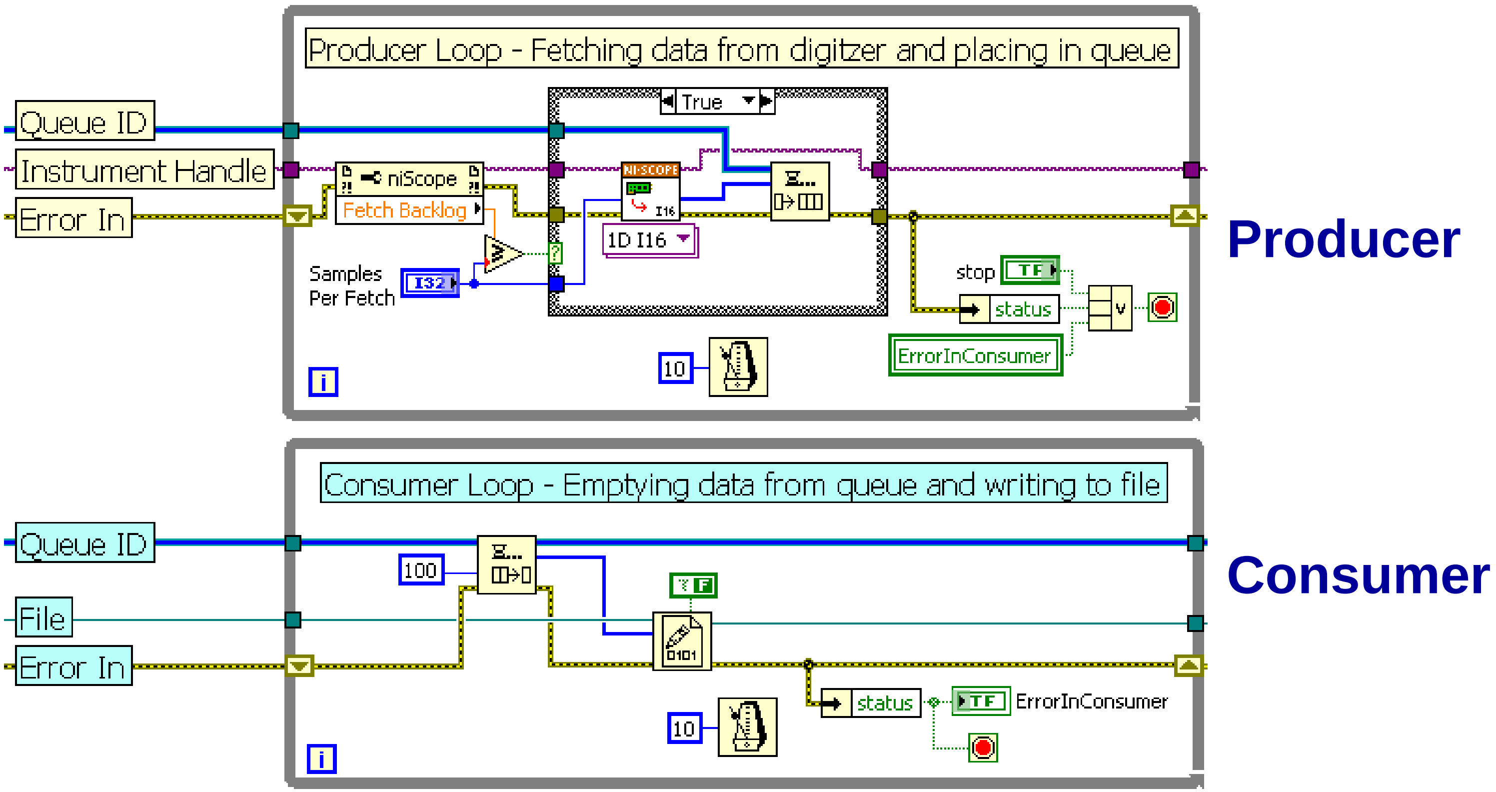
NI RAID solutions

PXI-8260	HDD-8263	HDD-8264
In-chassis, Three-slot PXI Express module	External, 2U height, 19 in. rack	External, 2U height, 19 in. rack
4-drive RAID 0	4-drive RAID 0	12 drive RAID 0
200 MB/s read/write	200 MB/s	600 MB/s
1 TB storage	1 TB storage	3 TB storage

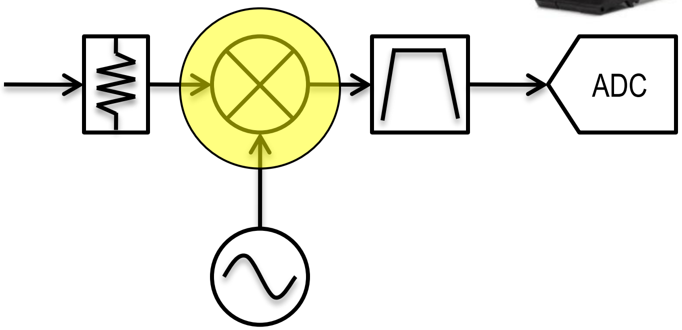
Technology 3: LabVIEW Multithreading

- Graphical programming simplifies streaming
- Parallel/multithreaded environment optimizes streaming



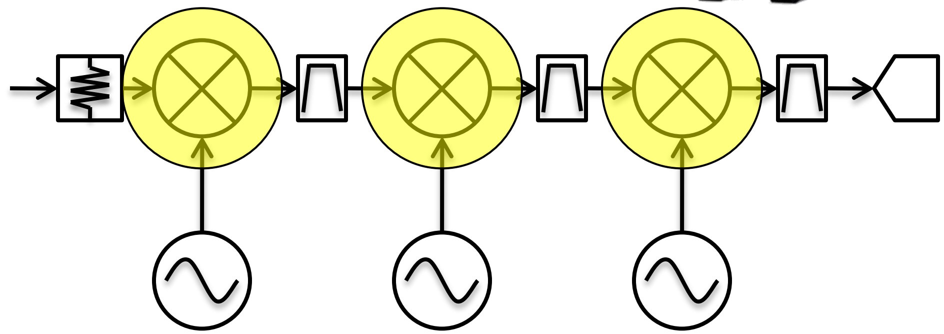
Single versus Superheterodyne Downconverter

Single-Stage Downconversion



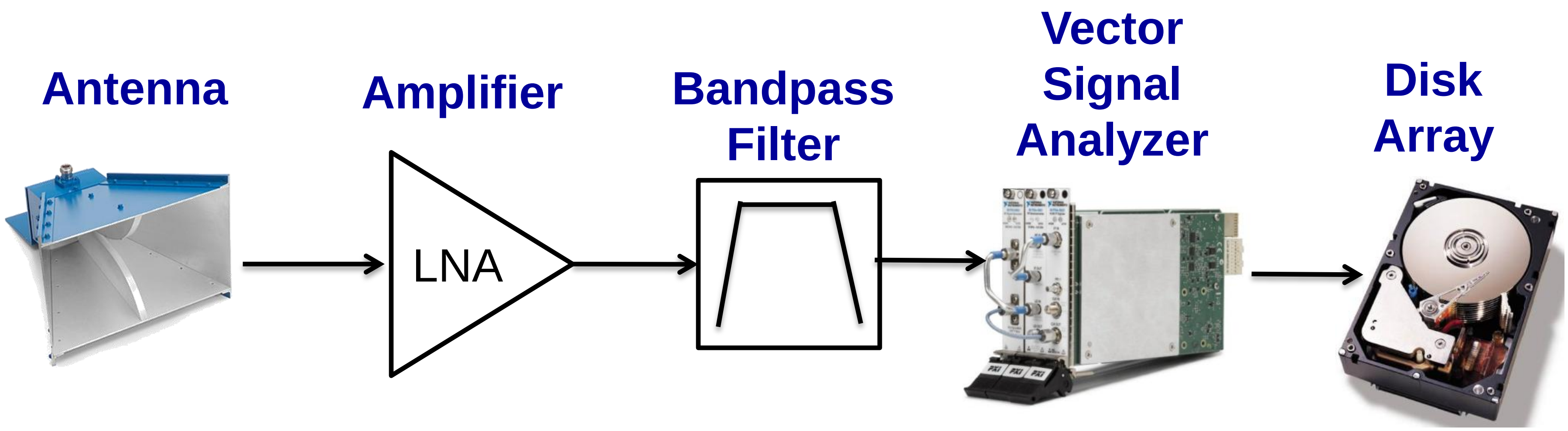
- Example = NI PXIe-5663
- Preselection always recommended
- Better noise floor

Superheterodyne Downconversion



- Example = NI PXI-5661
- Preselection sometimes required
- Better out-of-band and IF rejection

Off air RF Recording System with the NI PXI 5663 VSA



PXI Amplifier and Attenuator

- PXI-5691 Programmable Amplifier
  - 50 MHz to 8 GHz frequency range
  - Up to 60 dB total gain
  - Fixed gain path (>26 dB)
  - Programmable gain path (0-30 dB)
- PXI-5695 Programmable Attenuator
  - 50 MHz to 8 GHz frequency range
  - Up to 60 dB total attenuation
  - Fixed attenuator path (30 dB)
  - Programmable attenuator path (10 – 40 dB)

Example System: Averna URT

- Generates recorded and simulated signals
- Recording features
  - Integrated AGC
    - Reduces analyzer noise figure
    - Optimizes for dynamic range
  - Integrated attenuator
    - Improves playback noise floor
    - Adjusts to recorded signal level
- Simulation features
  - Multiple broadcast radio standards
  - Multiple broadcast video standards

Summary

- Many technologies use multiple RF ports
- Phase-coherent synchronization is a difficult test challenge
  - Instrumentation must share LO and sample clocks for best performance
  - Difficult to implement with inflexible instrumentation
- NI 6.6 GHz RF platform provides a modular phase-coherent solution