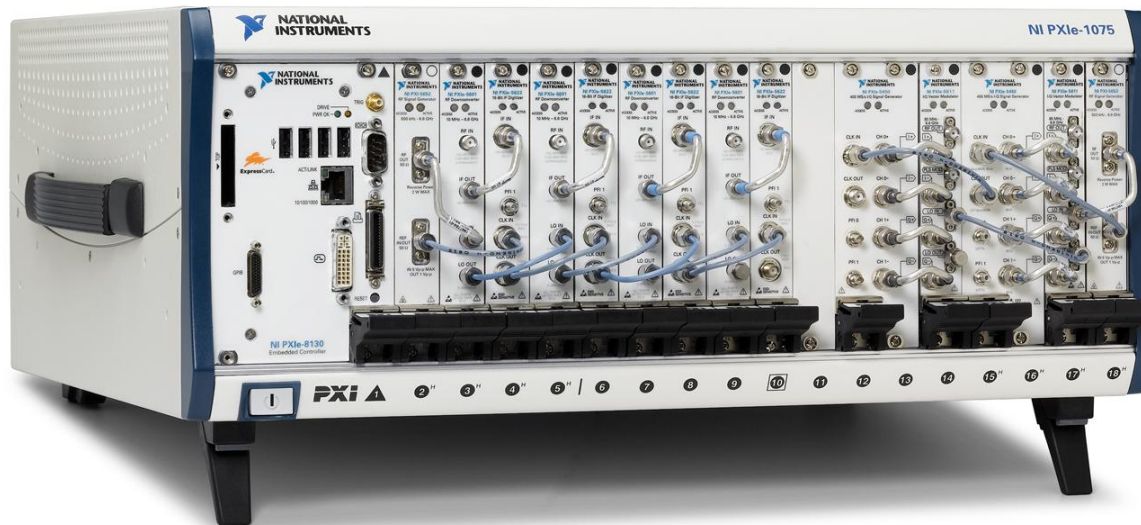




Configuring a Phase-Coherent RF Record and Playback System

Presented by Leif Johansson



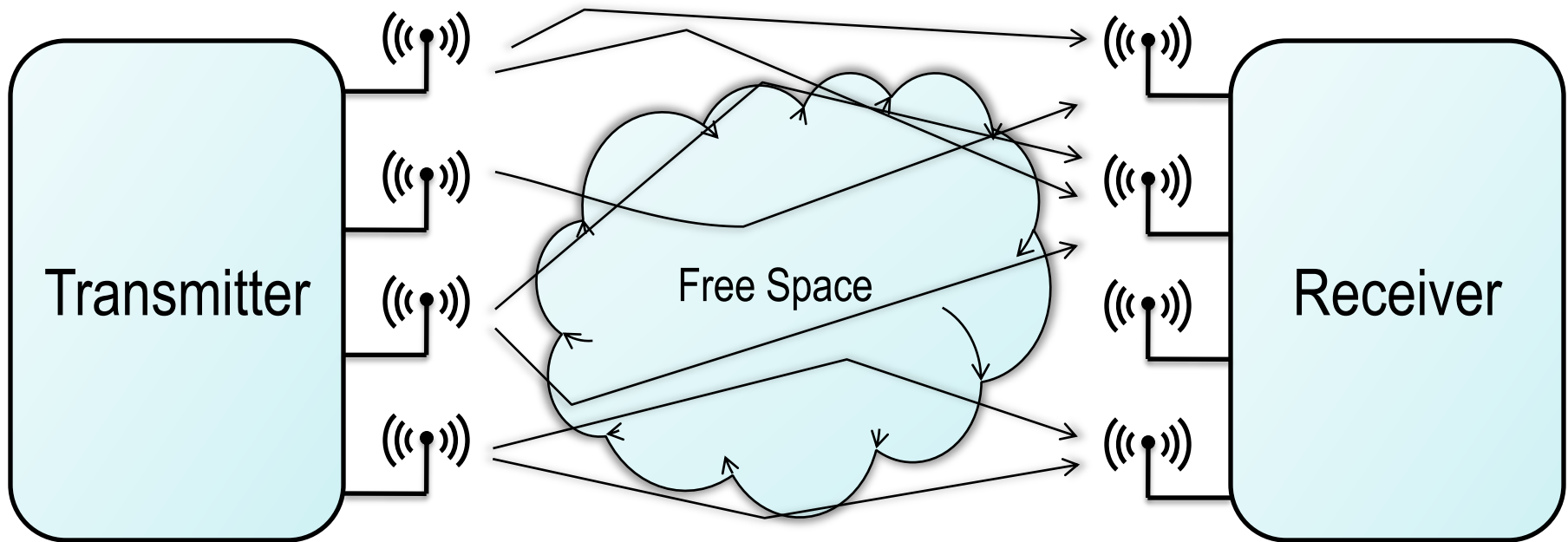
Agenda

- 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

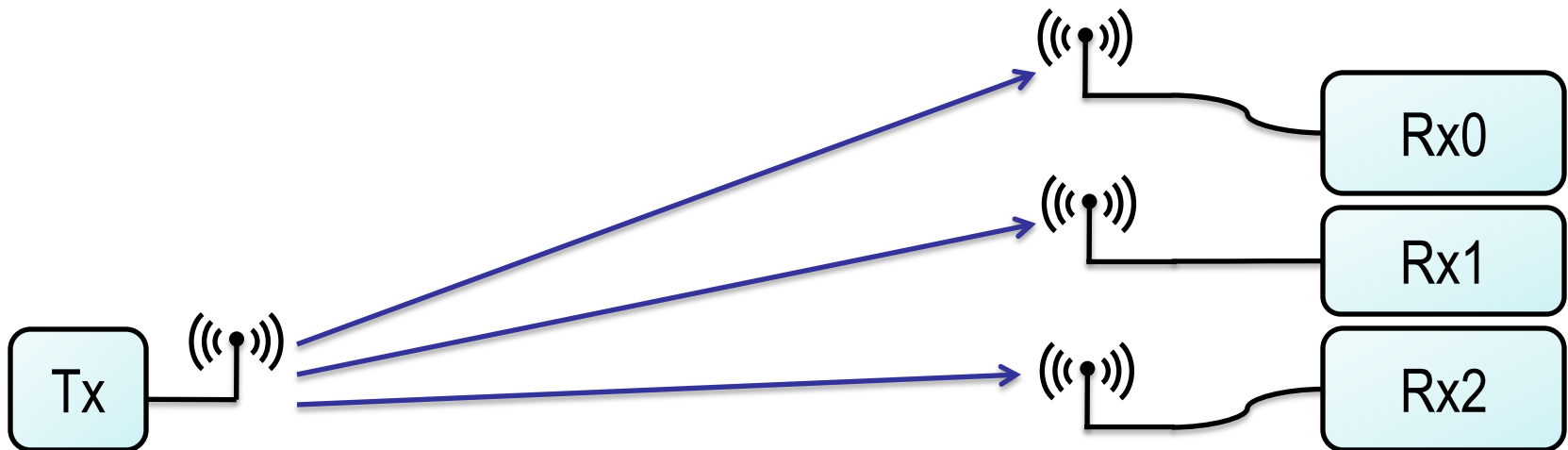
MIMO – Multiple Input, Multiple Output

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



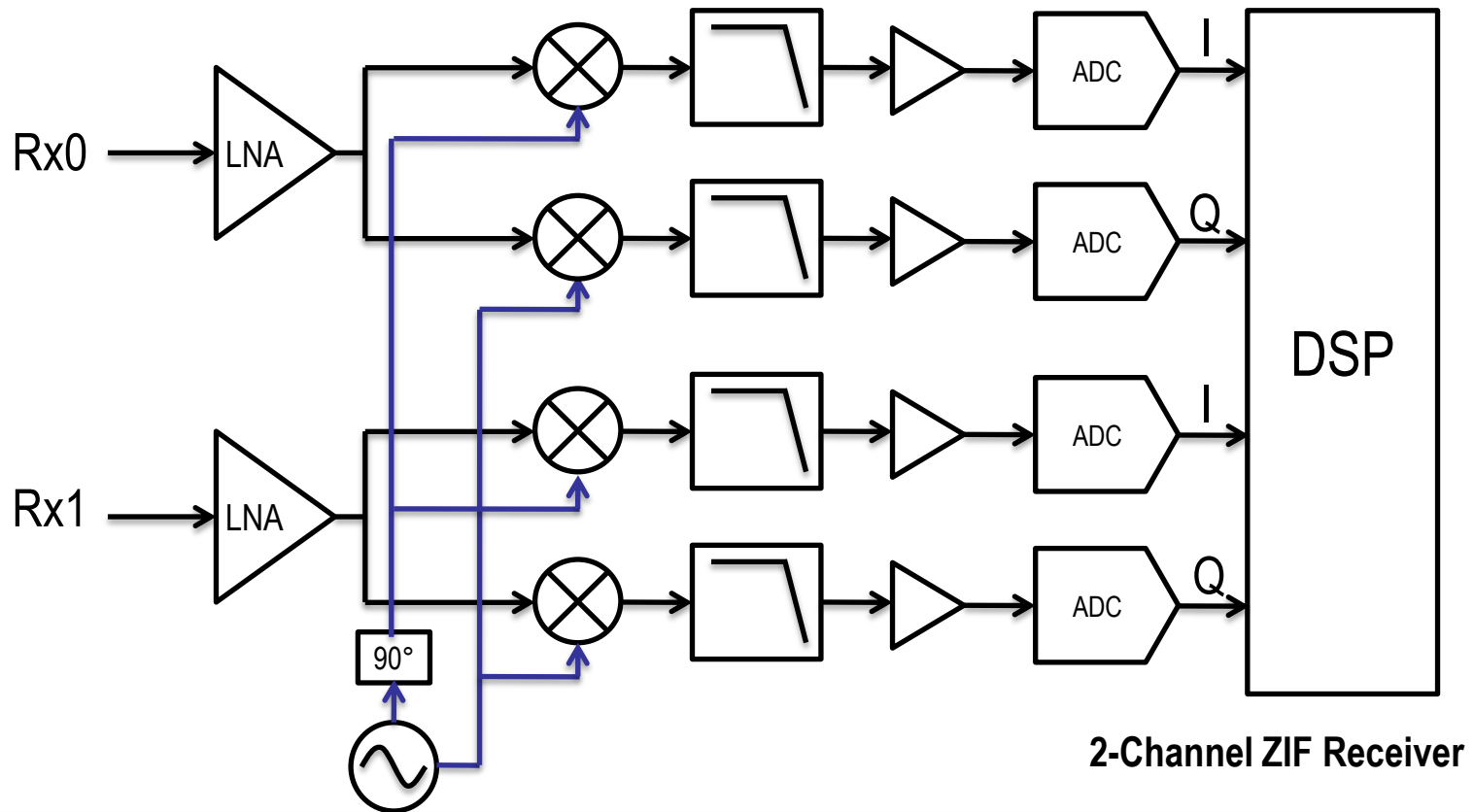
Direction Finding

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



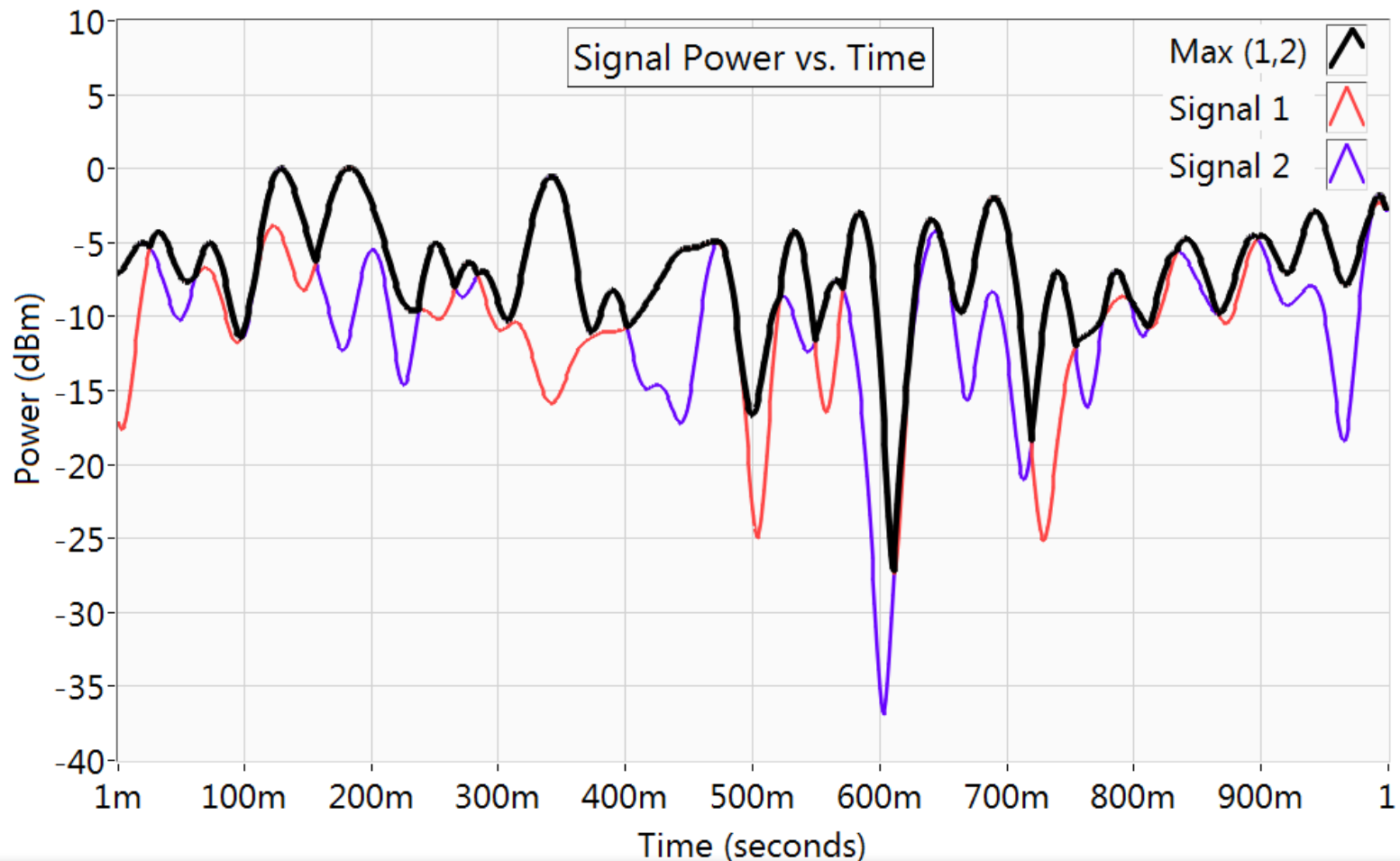
Antenna Diversity Receivers

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



Diversity and Signal Power

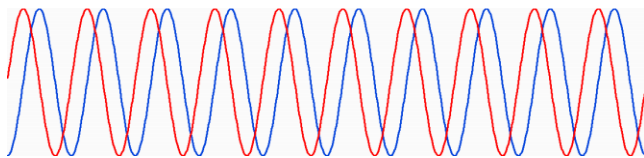
- Diversity increases receive signal strength



Step 1: RF Synchronization

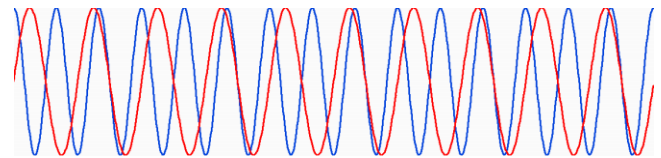
Phase Coherency Definition

- 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



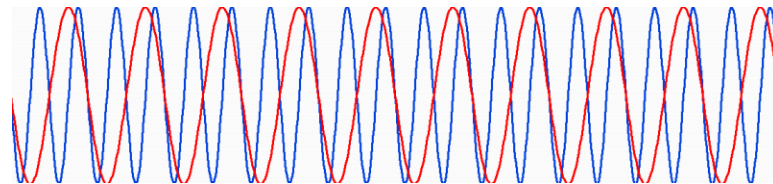
Same Frequency

versus



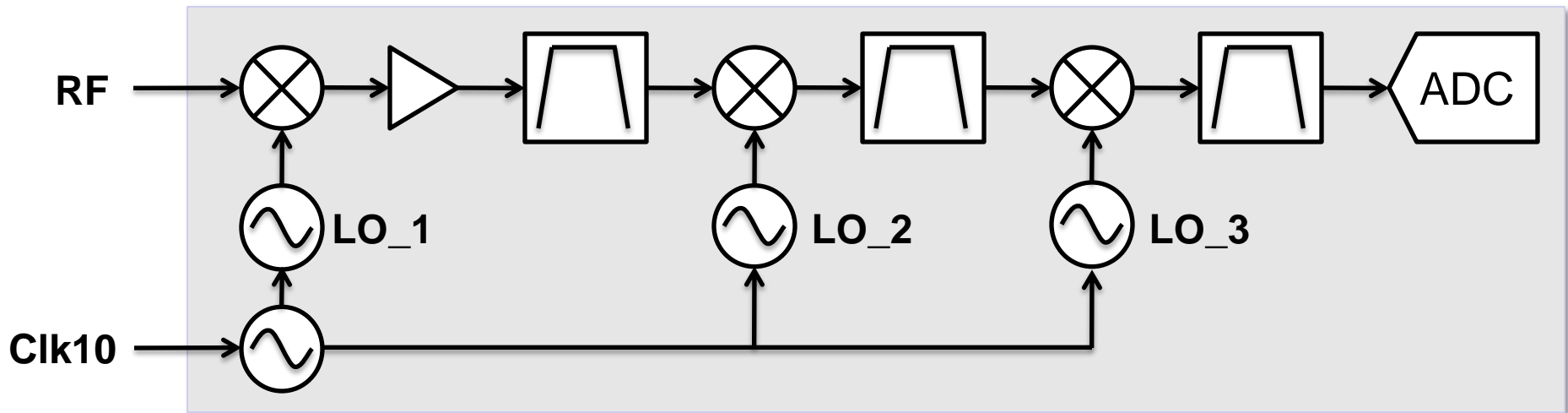
Different Frequencies

- 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.)

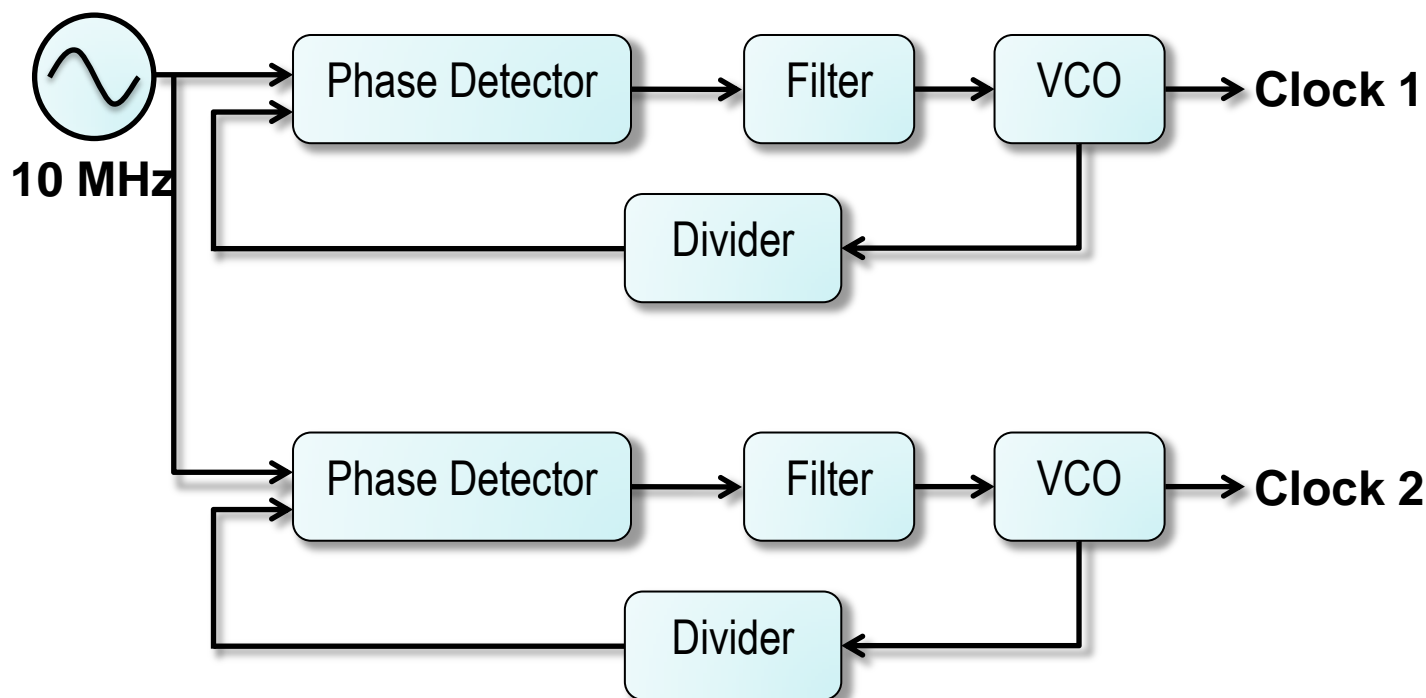


NI PXI-5661



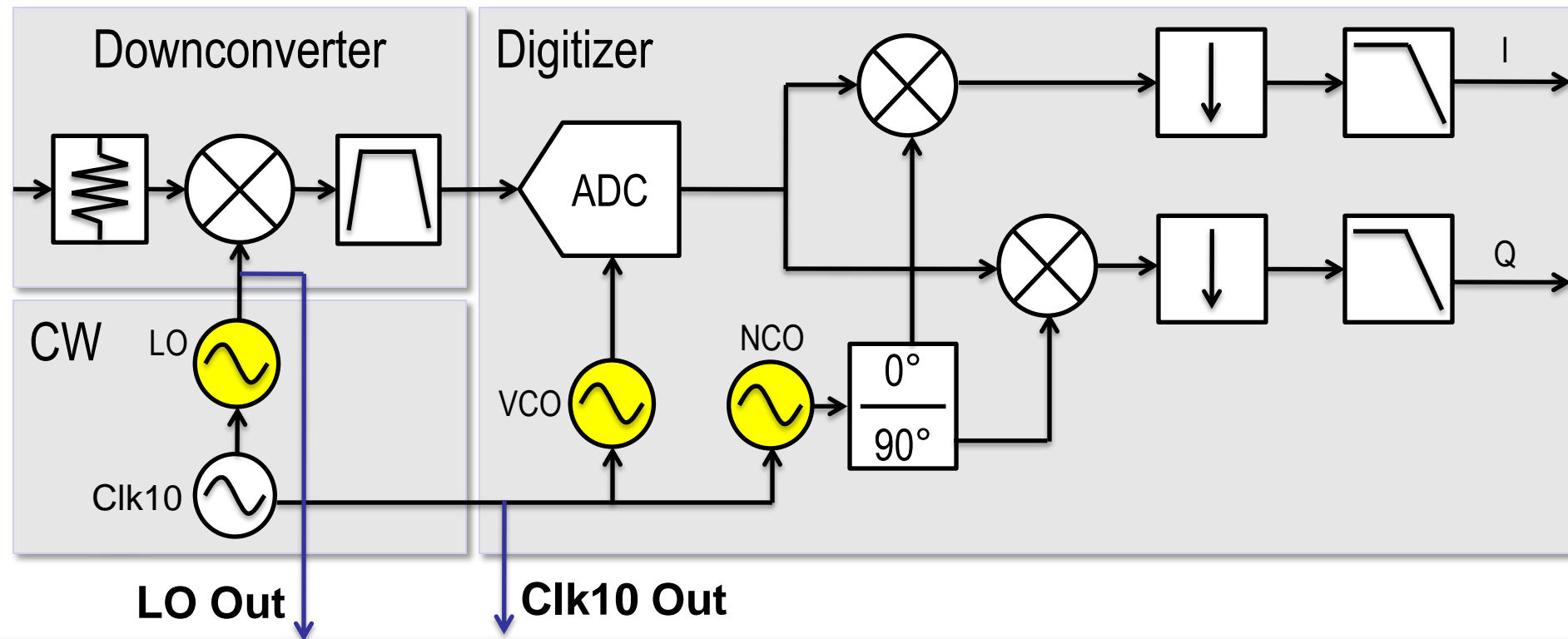
Shared Reference Clock

- 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

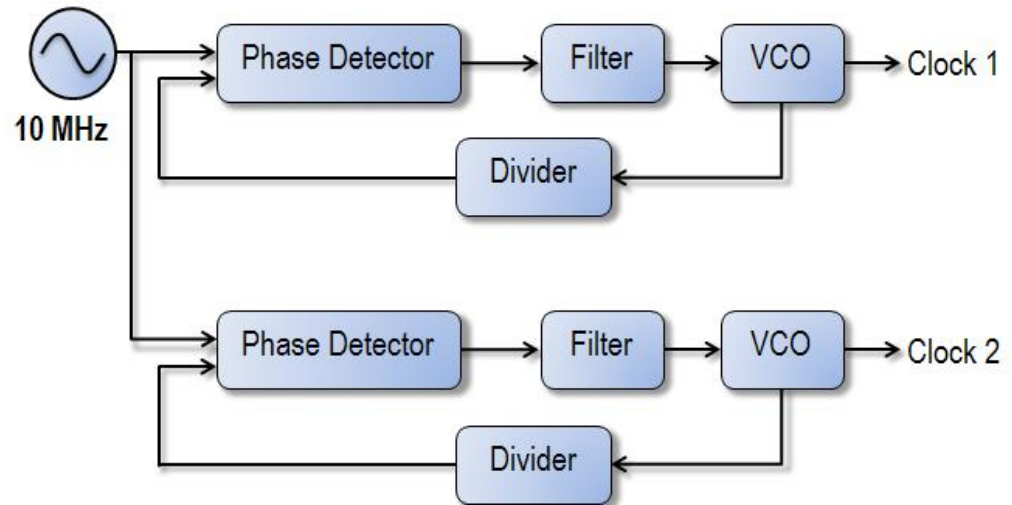
- Shared clocks include:
 - Local oscillator (LO derived from VCO)
 - ADC sample clock and DDC numerically controlled oscillator (NCO)



LO Clock Sharing Comparison

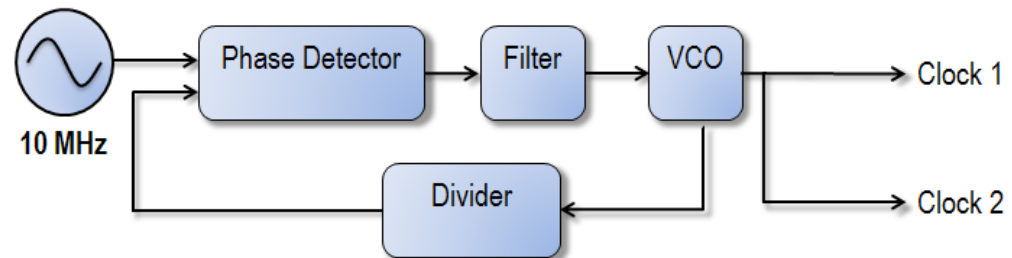
Shared Reference Clocks

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

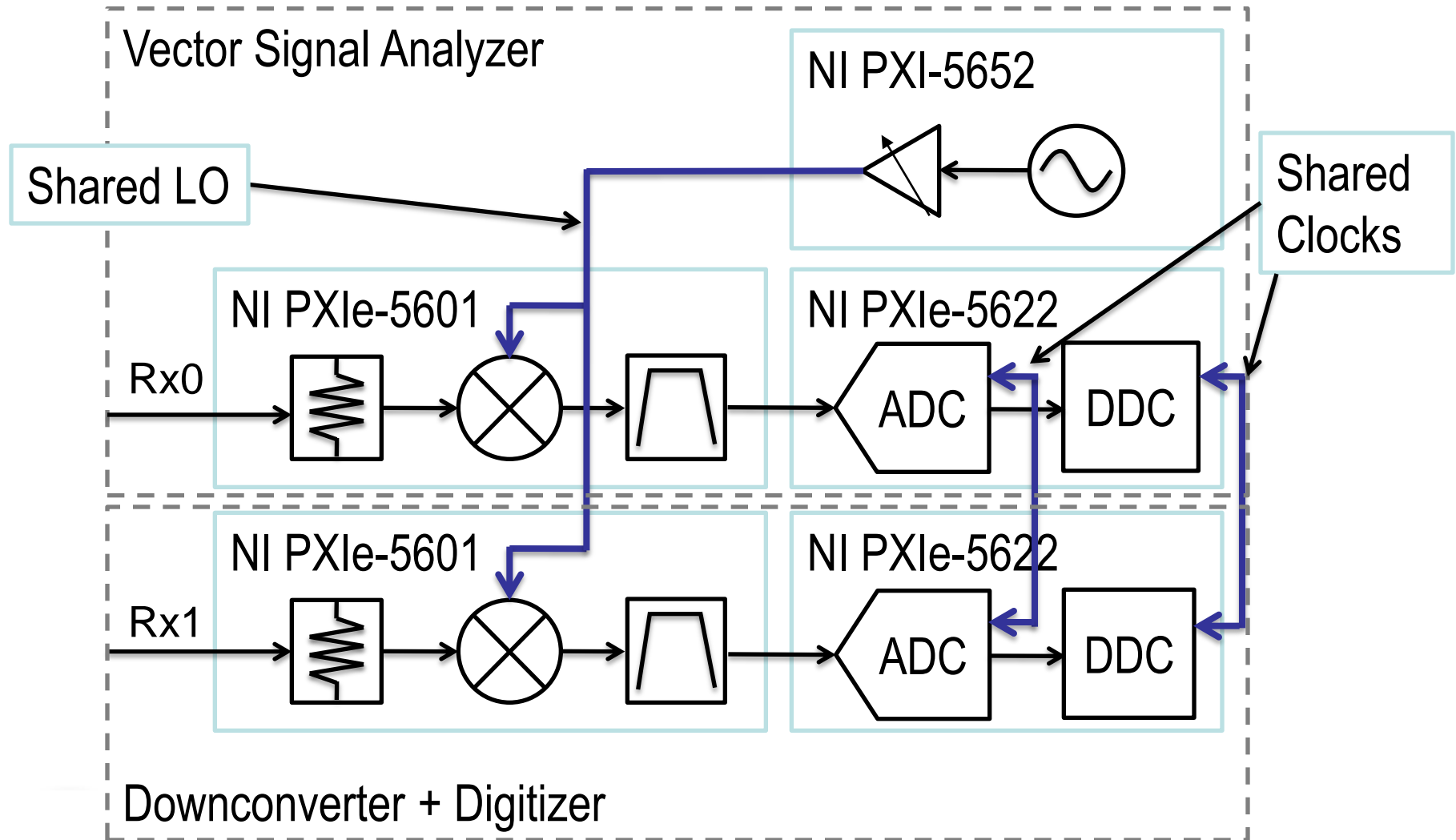


Shared LO and Sample Clocks

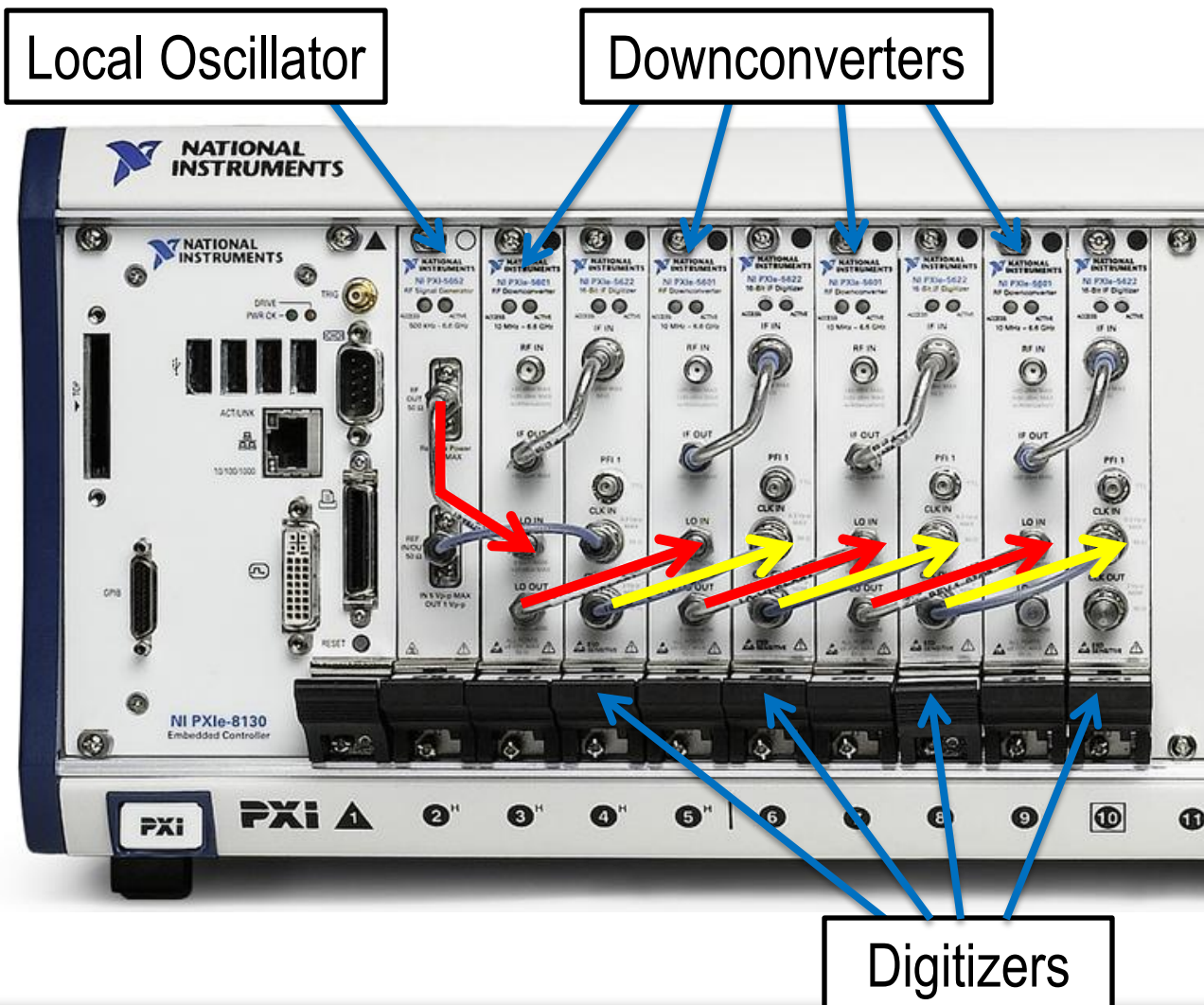
- One PLL per clock (master)
- Uncertainty from PLL phase noise and dividers correlated, cancels out
- **PREFERRED METHOD**



Phase Coherent x2 RF Acquisition



Four-Channel Phase-Coherent Acquisition



Shared LO

Shared ADC
Clock

Digitizers

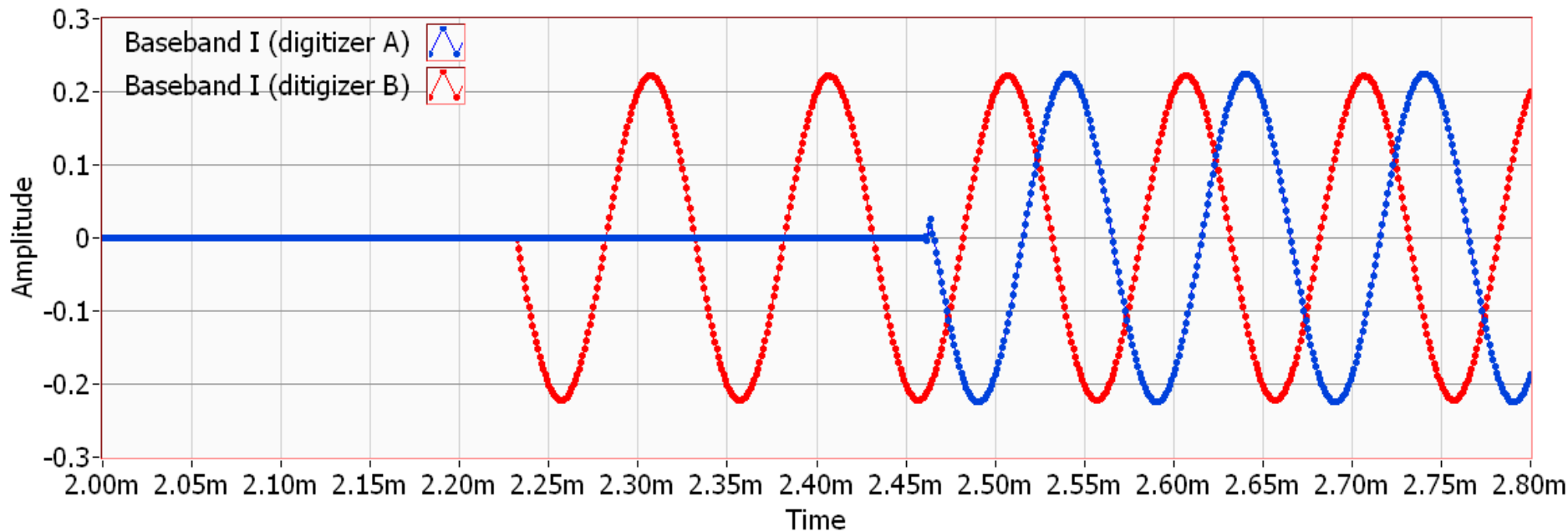
Other Synchronization Concerns

- 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

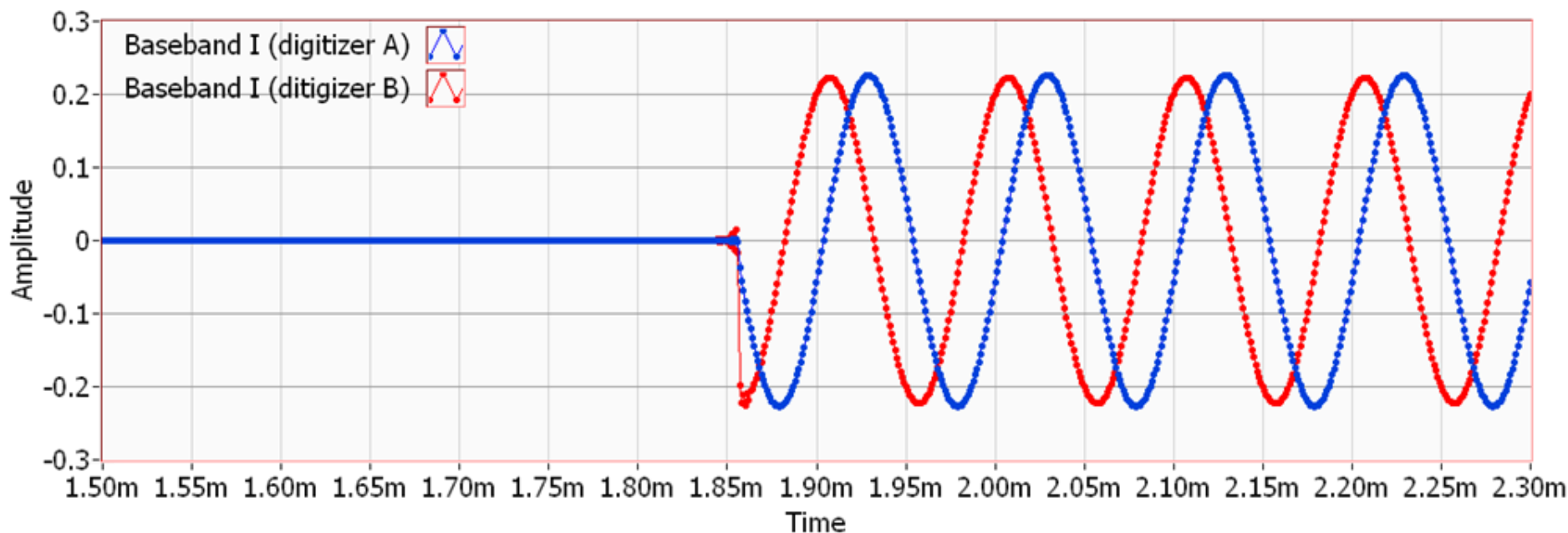
Baseband Signals without Shared Start Trigger



Synchronized and Not Calibrated

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

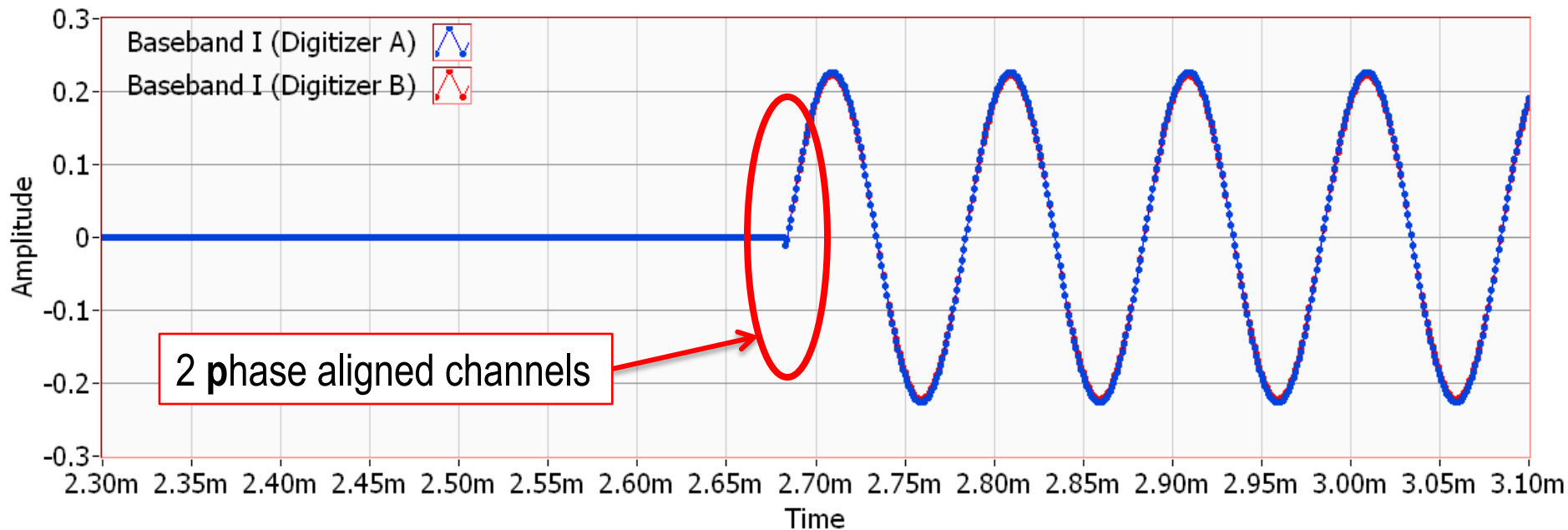
Baseband Signals with Shared Sample Start Trigger



Channels Synchronized and Aligned

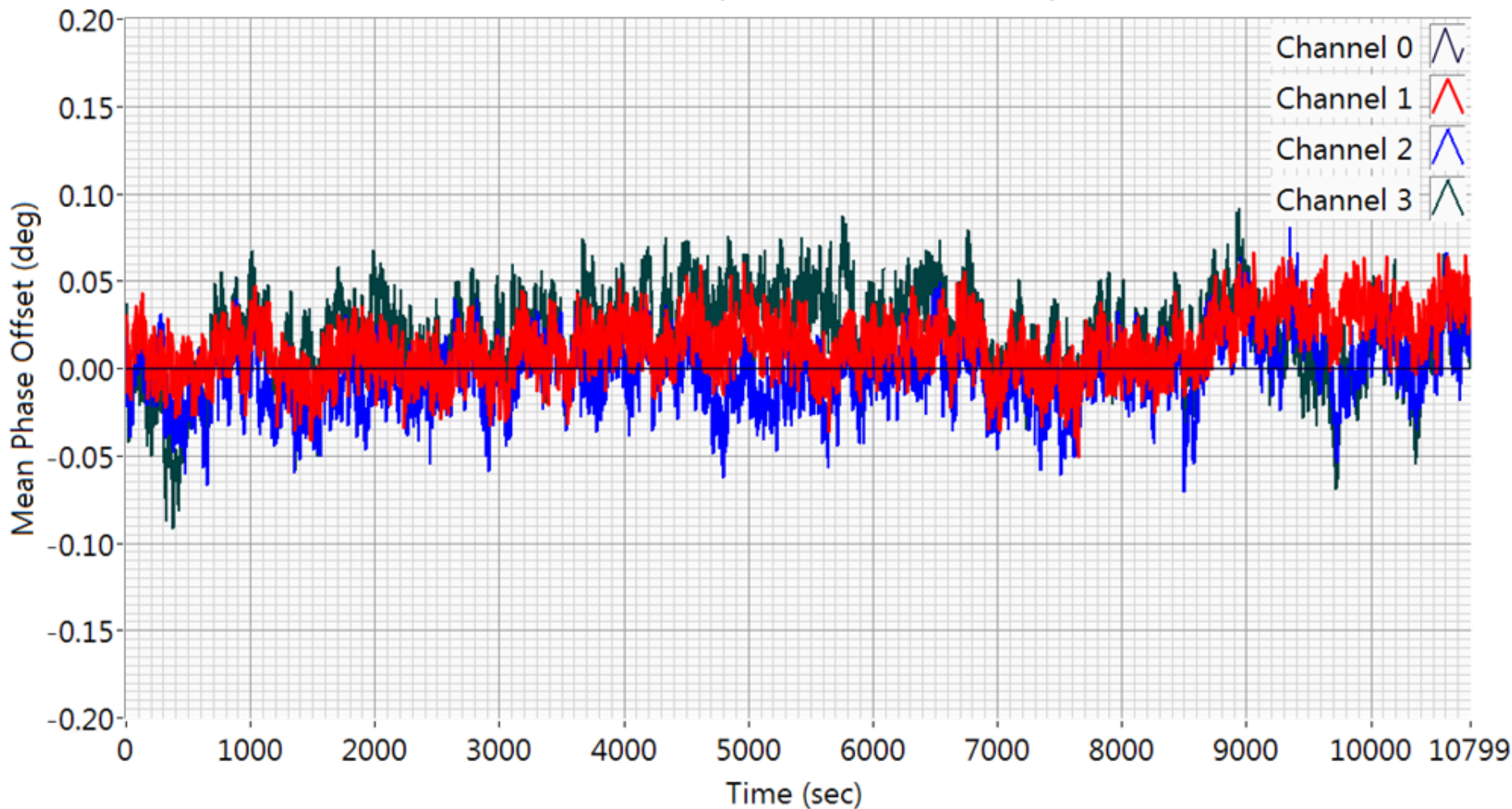
- Onboard signal processor (OSP) uses digital carrier called NCO
 - Can be manually adjusted per channel (VSA and VSG)
 - Compensates for channel-to-channel phase offset
 - 0.0055 degree phase adjust resolution

Fully Synchronized Baseband Signals



VSA Synchronization Stability

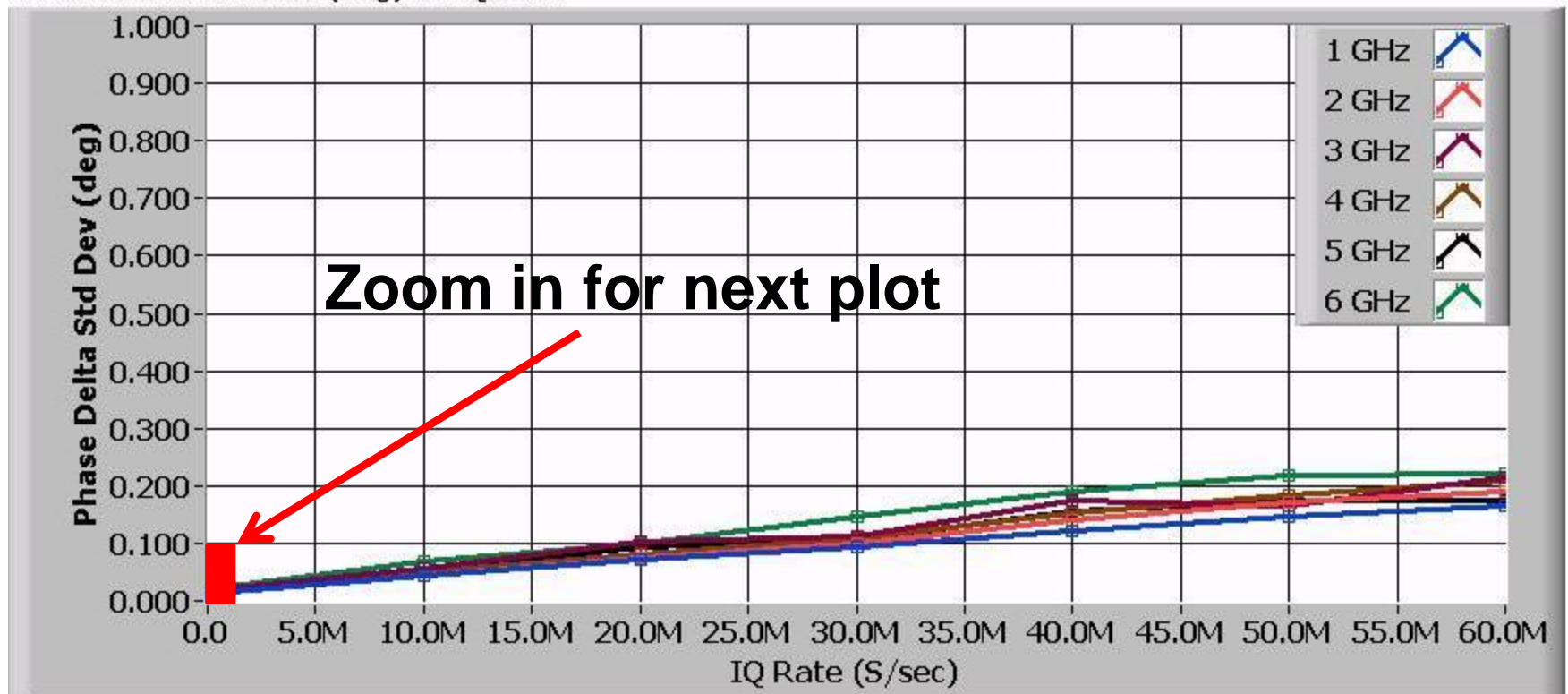
Mean LO Phase Offset at 2.4 GHz (4 PXIe-5663 Channels) over 3 Hours



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)**

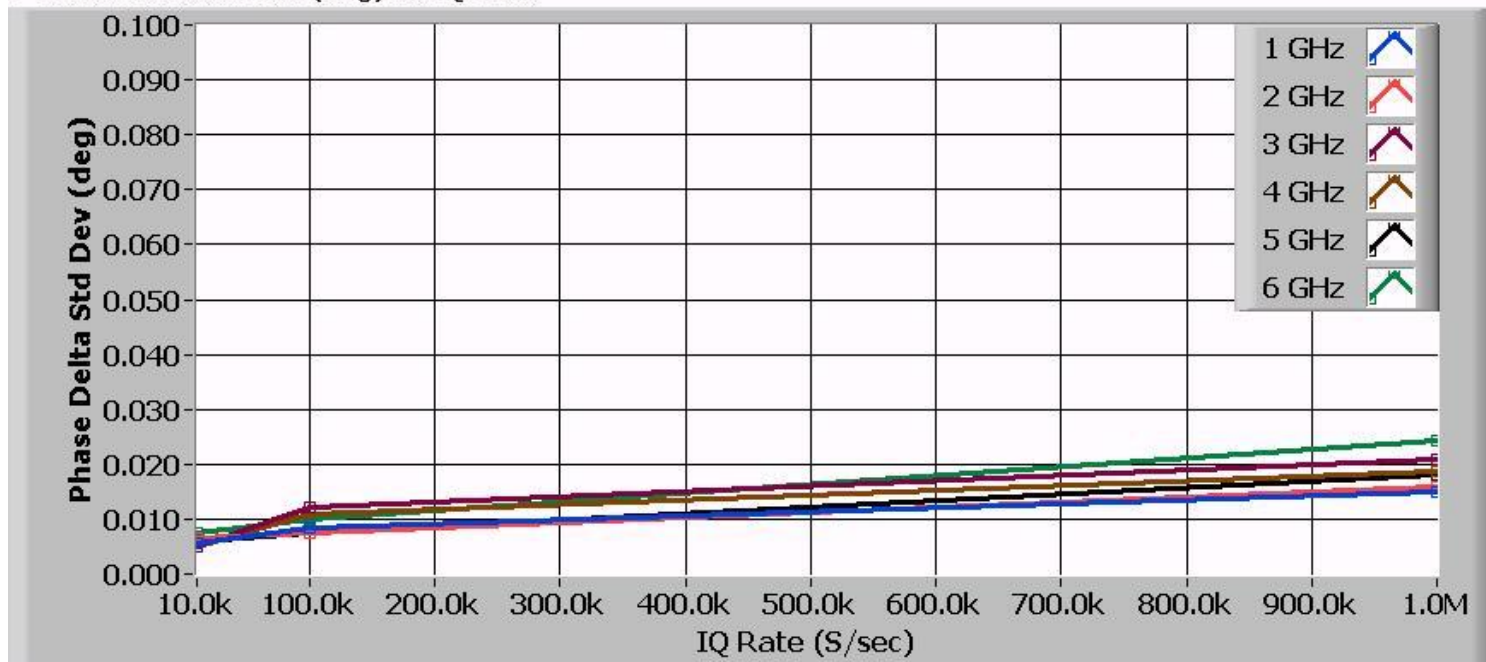
Phase Delta Std Dev (deg) vs IQ Rate



Phase-Coherency Performance Plots – VSAs

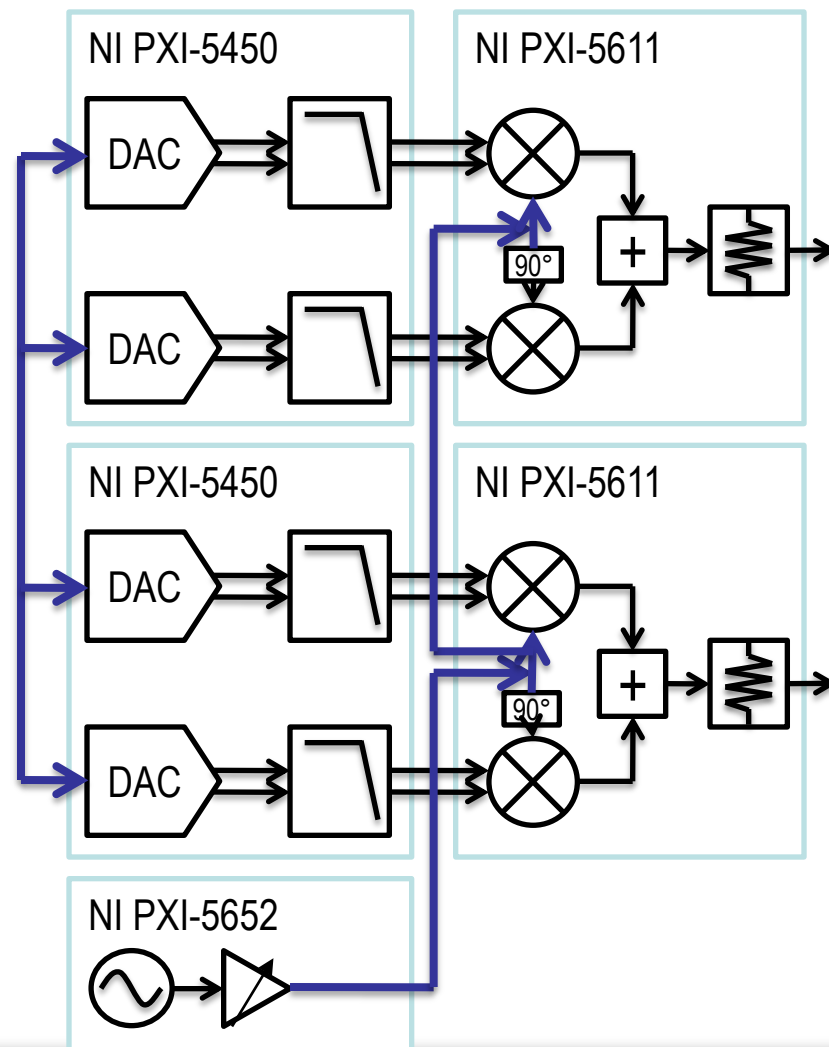
- Full scale input to two NI PXle-5663 VSAs (0 dBm CW, 0 dBm ref level)
- **Plot below zooms in relative to prior plot (IQ Rates ≤ 1.0 MS/s)**
- Y scale max is now 0.1 degree (prior plot Y scale max is 1 degree)

Phase Delta Std Dev (deg) vs IQ Rate

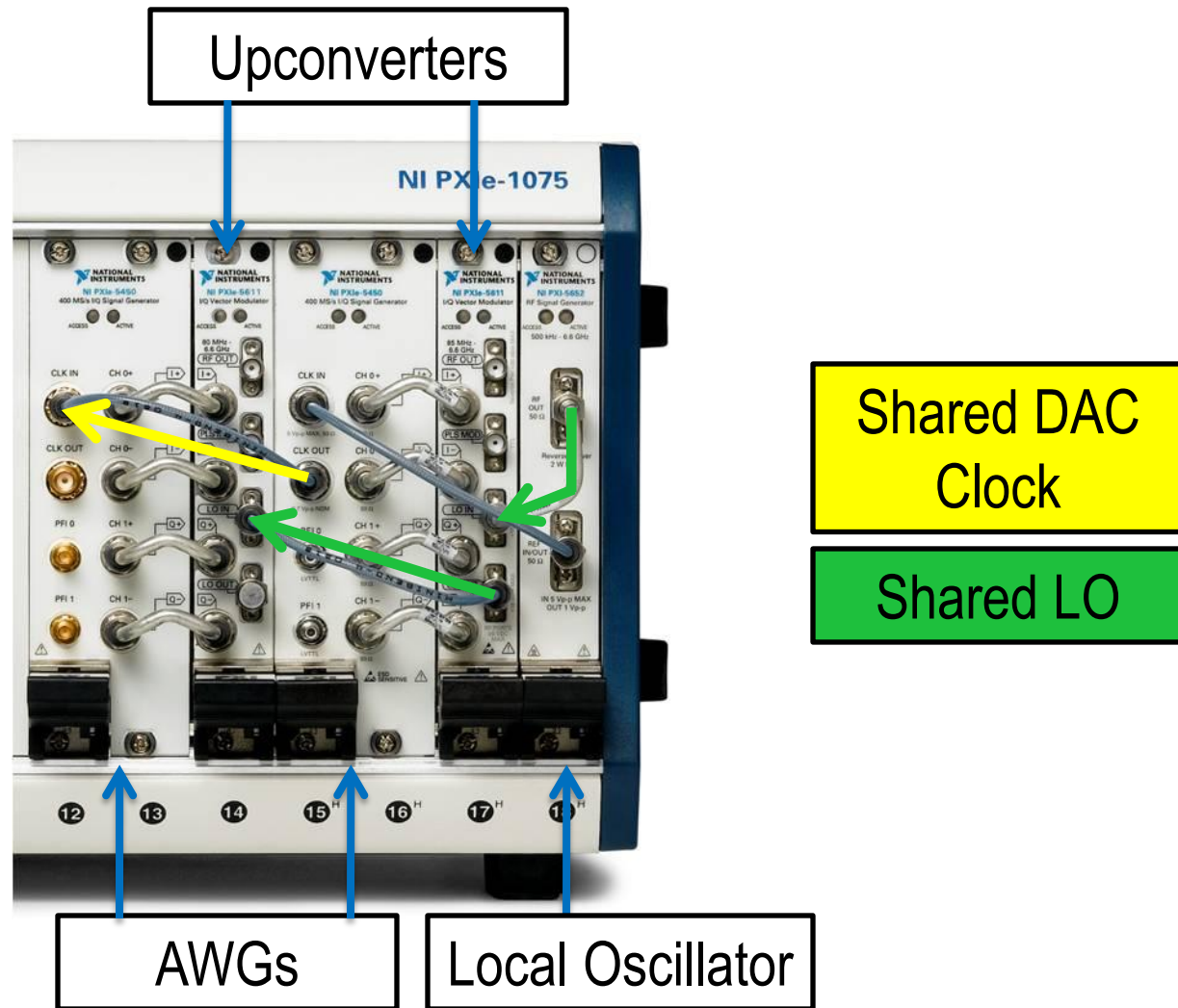


Synchronizing RF Signal Generators

- 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



Step 2: Record and Playback

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*

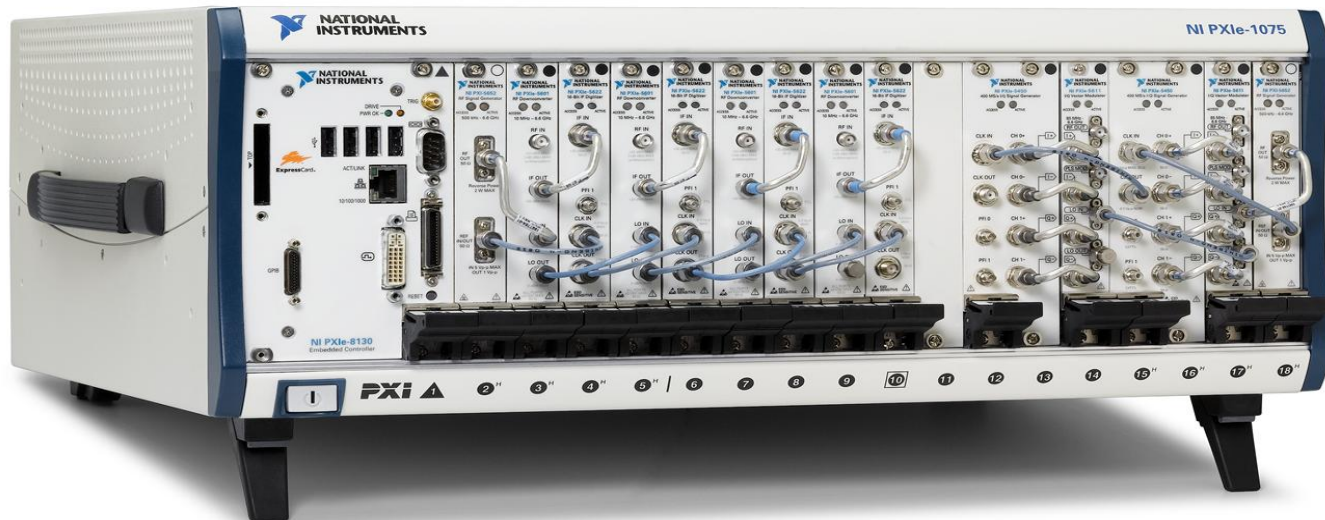
- 50 MHz bandwidth (62.5 MS/s)
- 300 MB/s
- Record for 2.0+ hours
- May require preselection



NI PXIe-5673 *from disk*

- 100 MHz bandwidth (125 MS/s)
- 400 MB/s
- Playback for 1.25+ hours
- Large waveforms can also be created in software

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

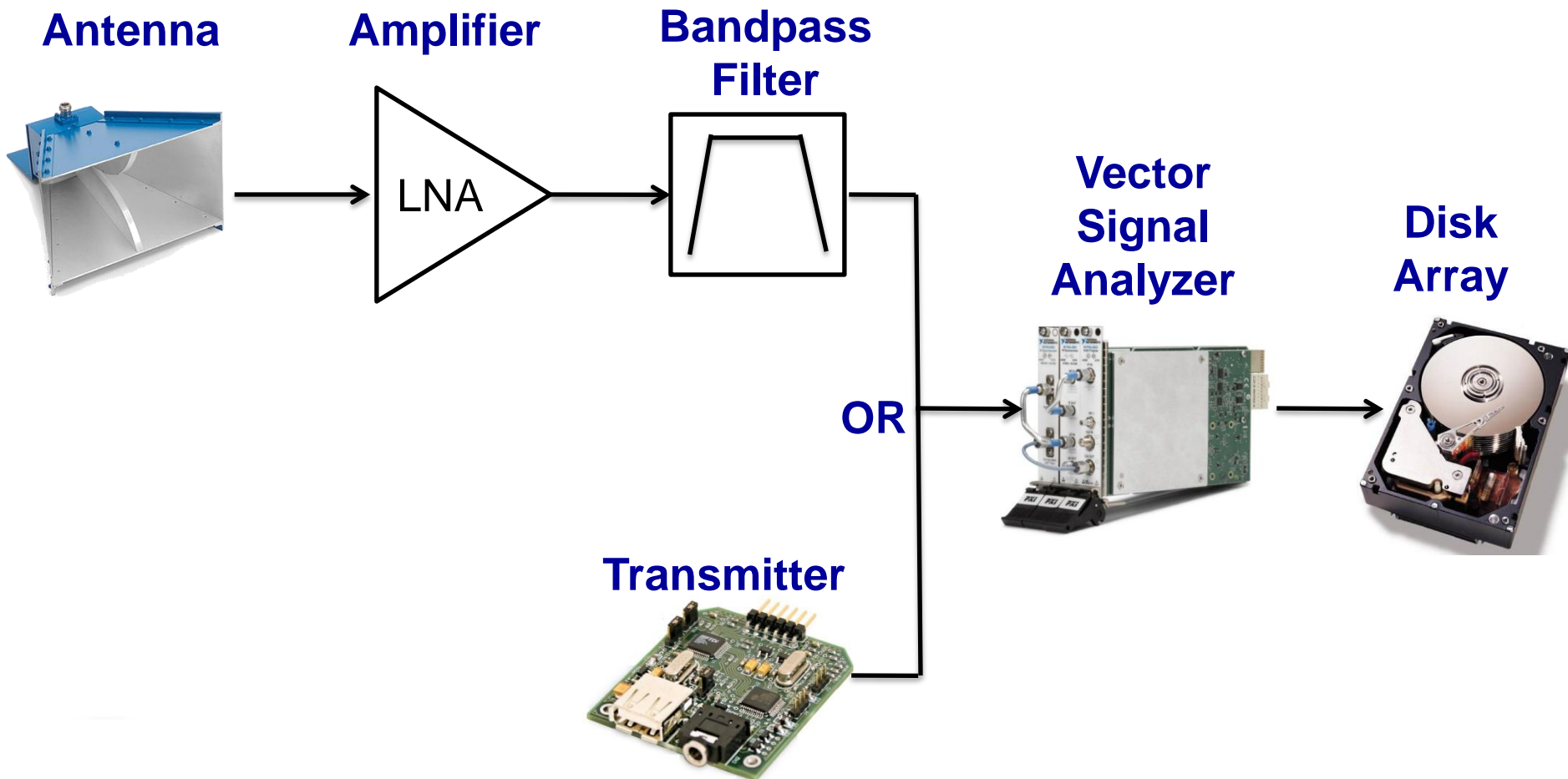


PCI/PXI Express to get the bandwidth needed



- 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)

Overview of an RF Recording System



Key Recording Technologies

High-Speed Bus

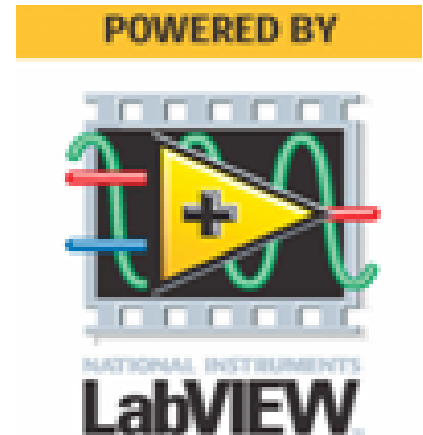
PCI  EXPRESS[®]

PXI

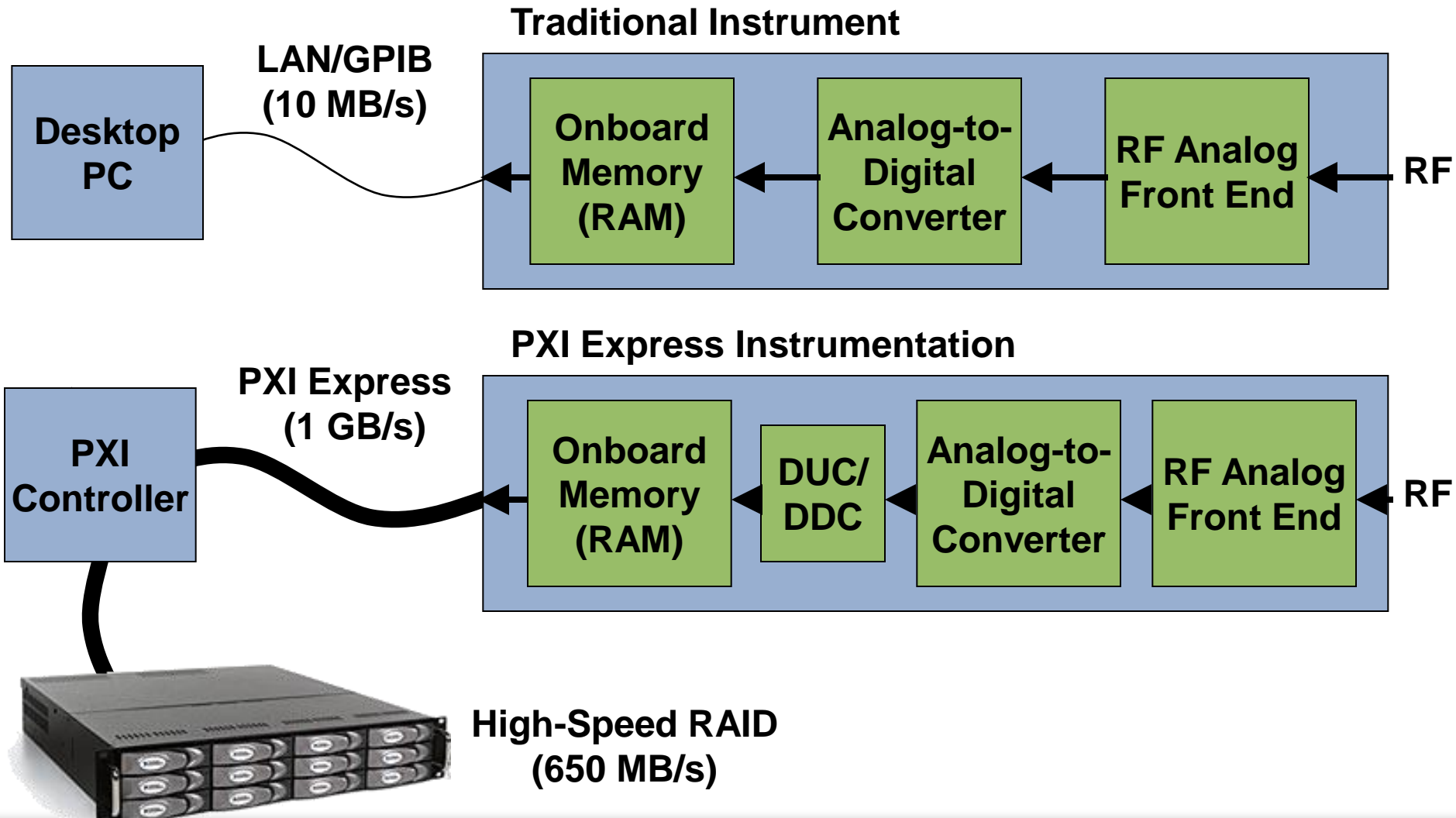
High-Speed Disk



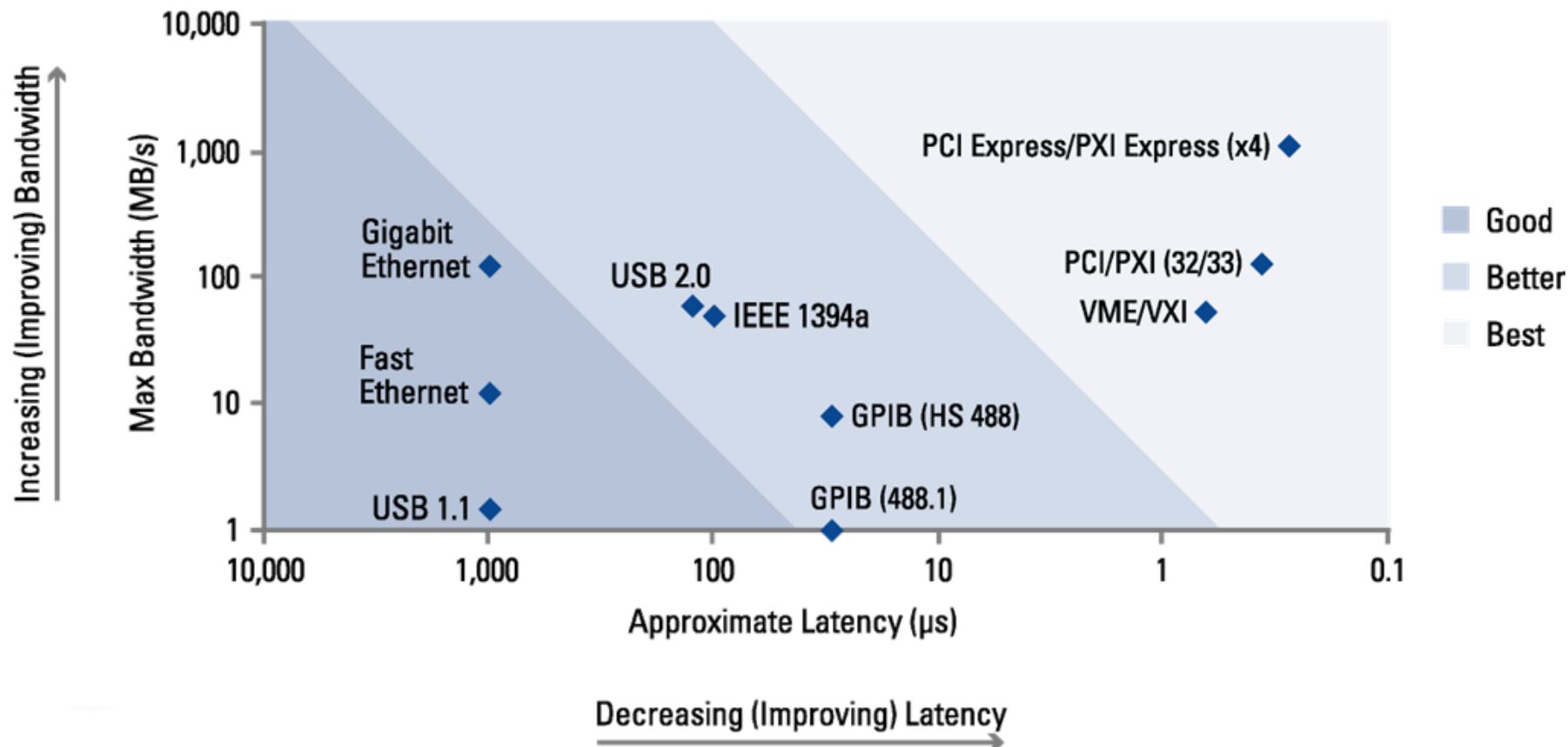
NI LabVIEW
Example Code



Instrument Architecture – VSA

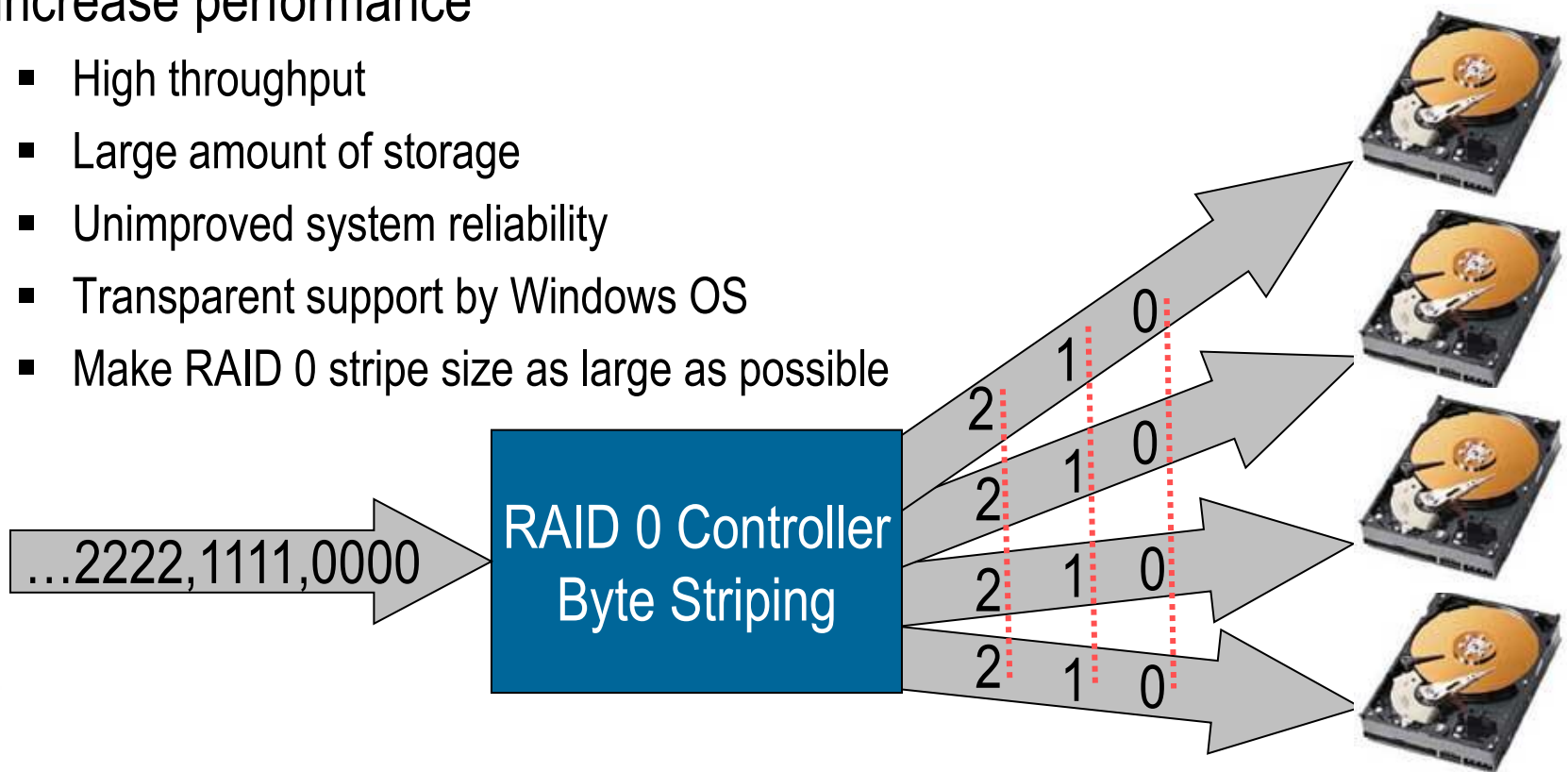


Technology 1: High-Speed Data Bus



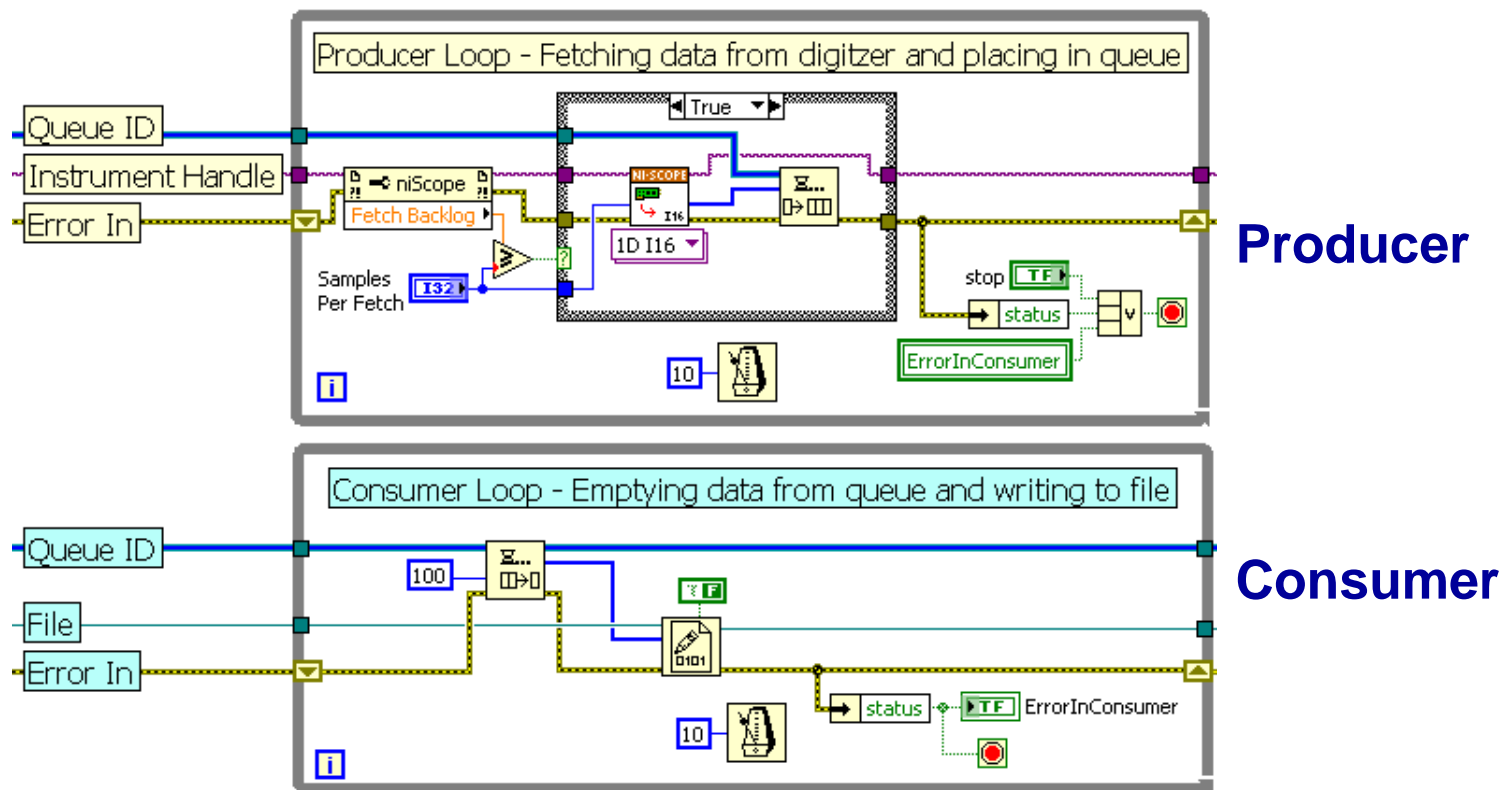
Technology 2: RAID

- 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



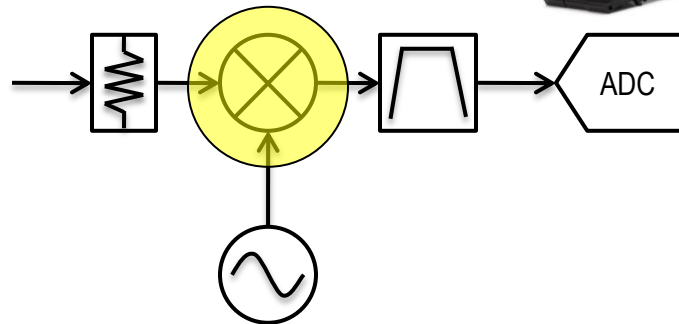
Technology 3: LabVIEW Multithreading

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



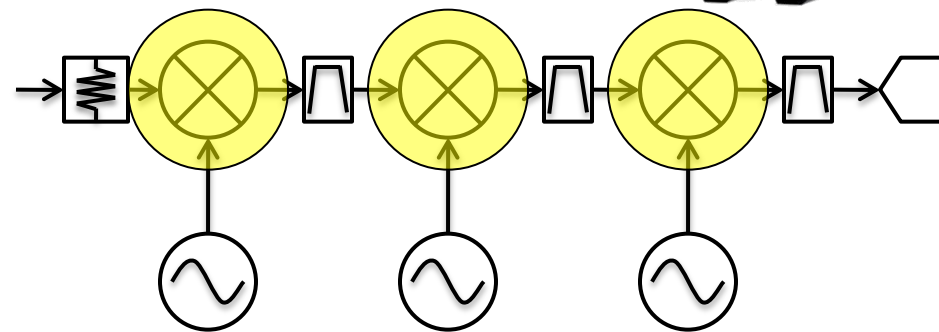
Single versus Superheterodyne Downconverter

Single-Stage Downconversion



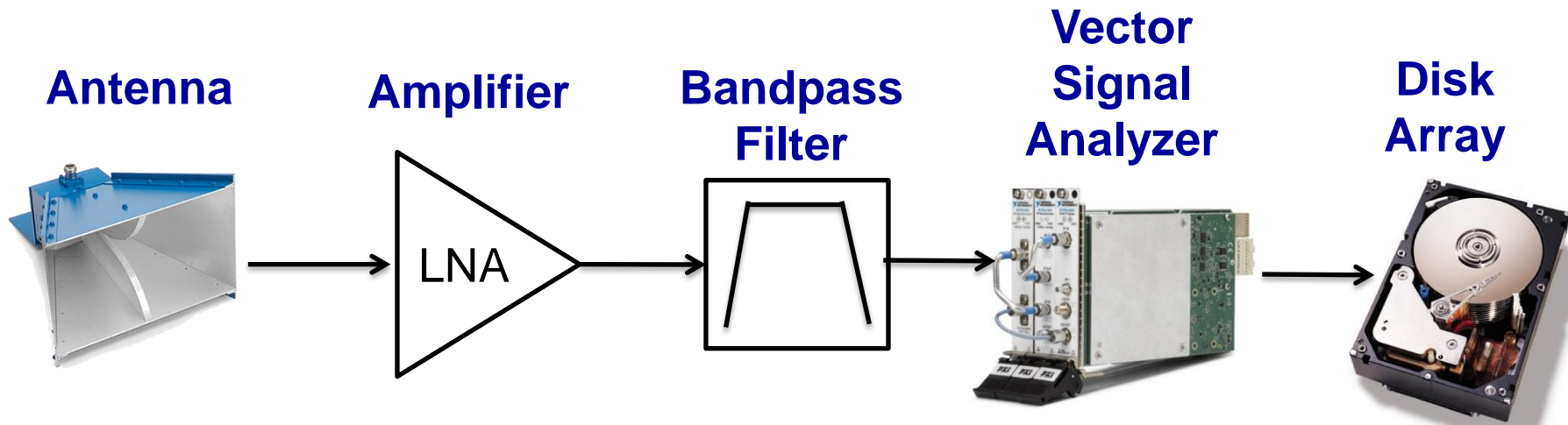
- Example = NI PXIe-5663
- Preselection always recommended
- Better noise floor

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)



Math Stuff: Signal Bandwidth to Duration

- RF bandwidth = $0.8 \times \text{I/Q rate}$
 - For example, 50 MS/s = **40 MHz** real-time bandwidth
 - Conversion artifact of digital downconversion
- Data rate = 4 bytes per sample \times I/Q rate (samples/s)
 - Each sample = 2 bytes for I and 2 bytes for Q
 - 40 MHz = 50 MS/s \times 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

Example System: Aversa 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

