NIDays09

WORLDWIDE GRAPHICAL SYSTEM DESIGN

CONFERENCE

NATIONAL INSTRUMENTS

# Recording RF Signals Off of the Air: Advanced Techniques and Applications

# Agenda

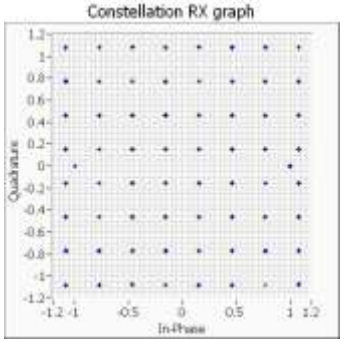
- Overview
- Key Technologies
  - High-speed data bus
  - High-speed RAID volumes
  - Parallel programming structures
- Configuring the RF Front End
- Example Applications

# RF Record and Playback

**Broadcast**


**Cellular**


**WiMAX**

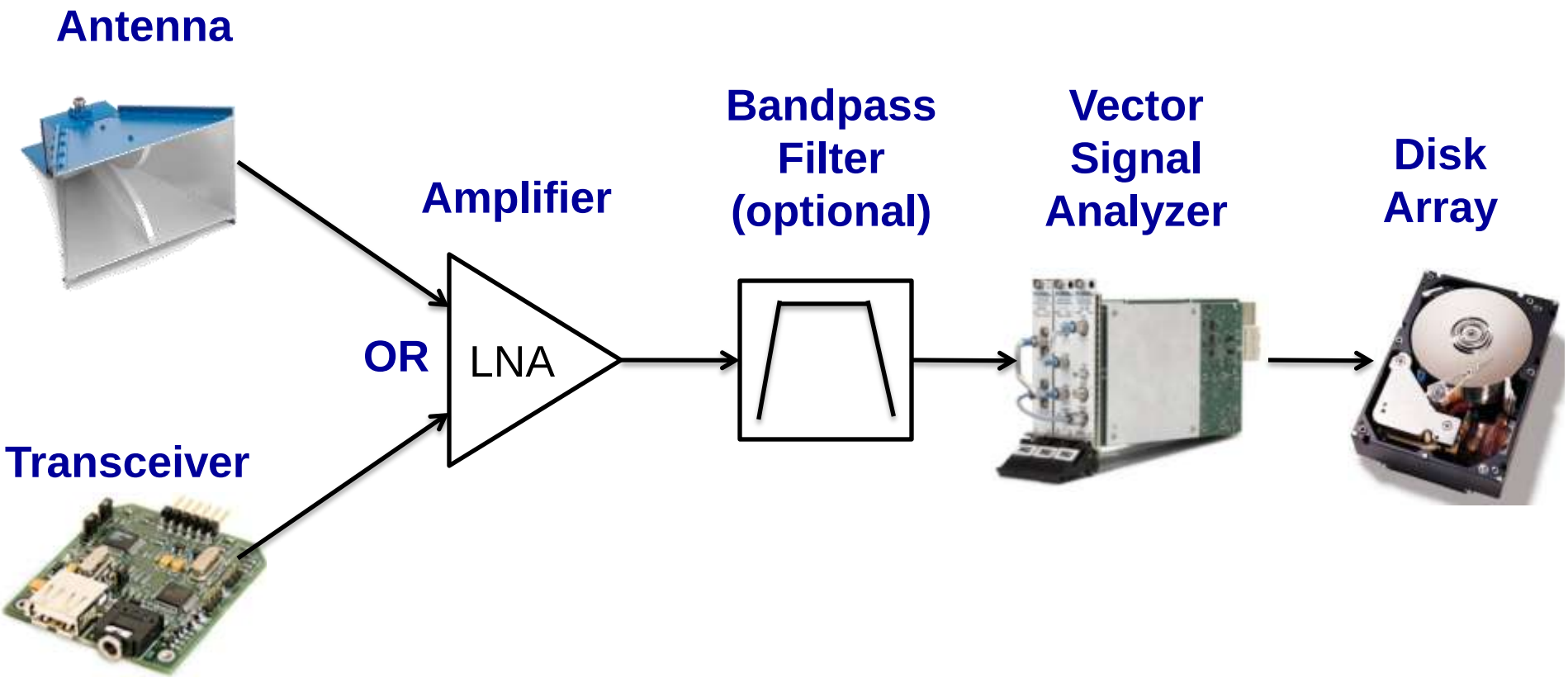



**Streaming**

**GPS**


**WLAN**

# RF Recording System Overview



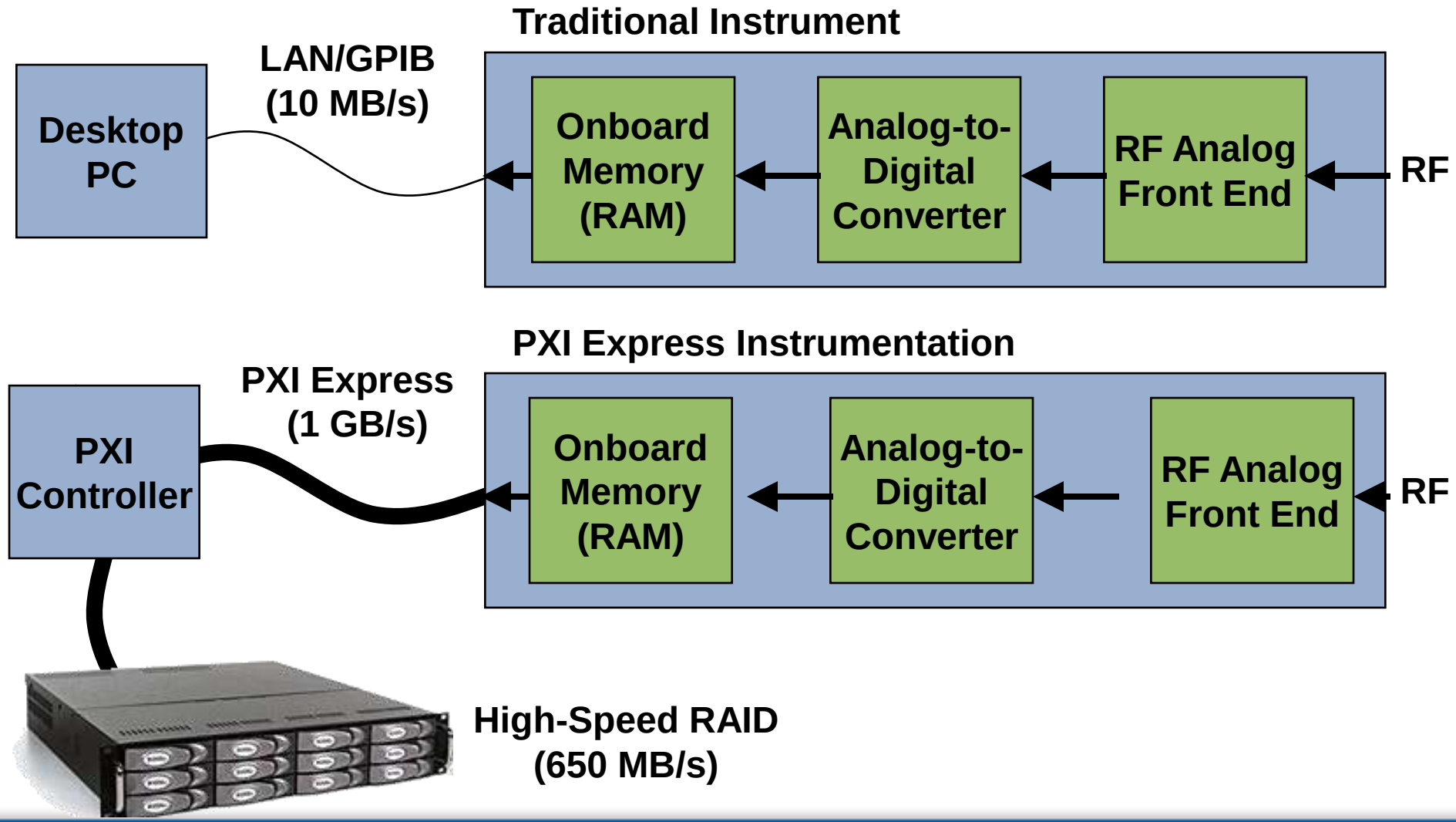
# Three Key Technologies

**High-Speed Bus**

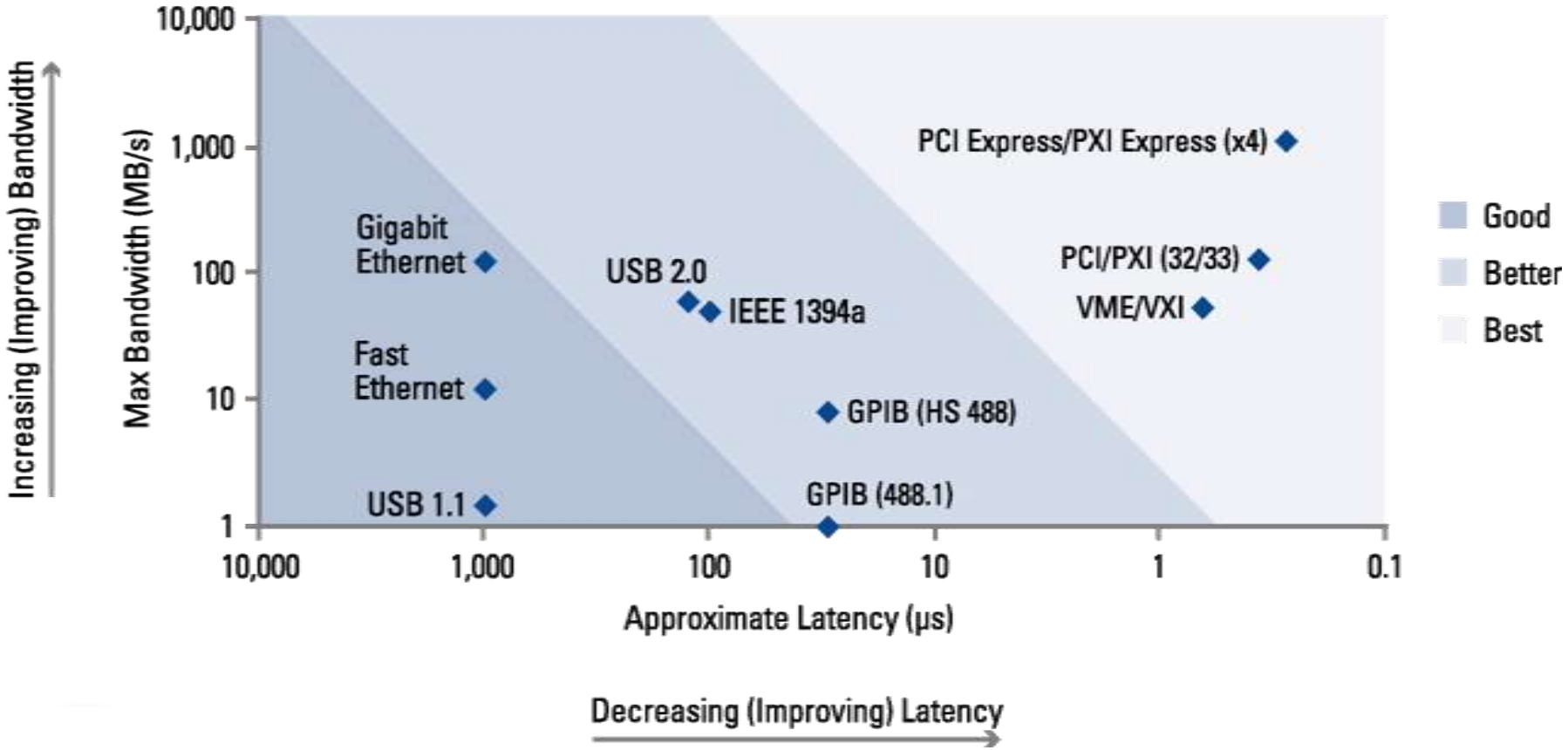
**High-Speed Disk**

**Parallel Programming in NI LabVIEW**

# Instrument Architecture – VSA

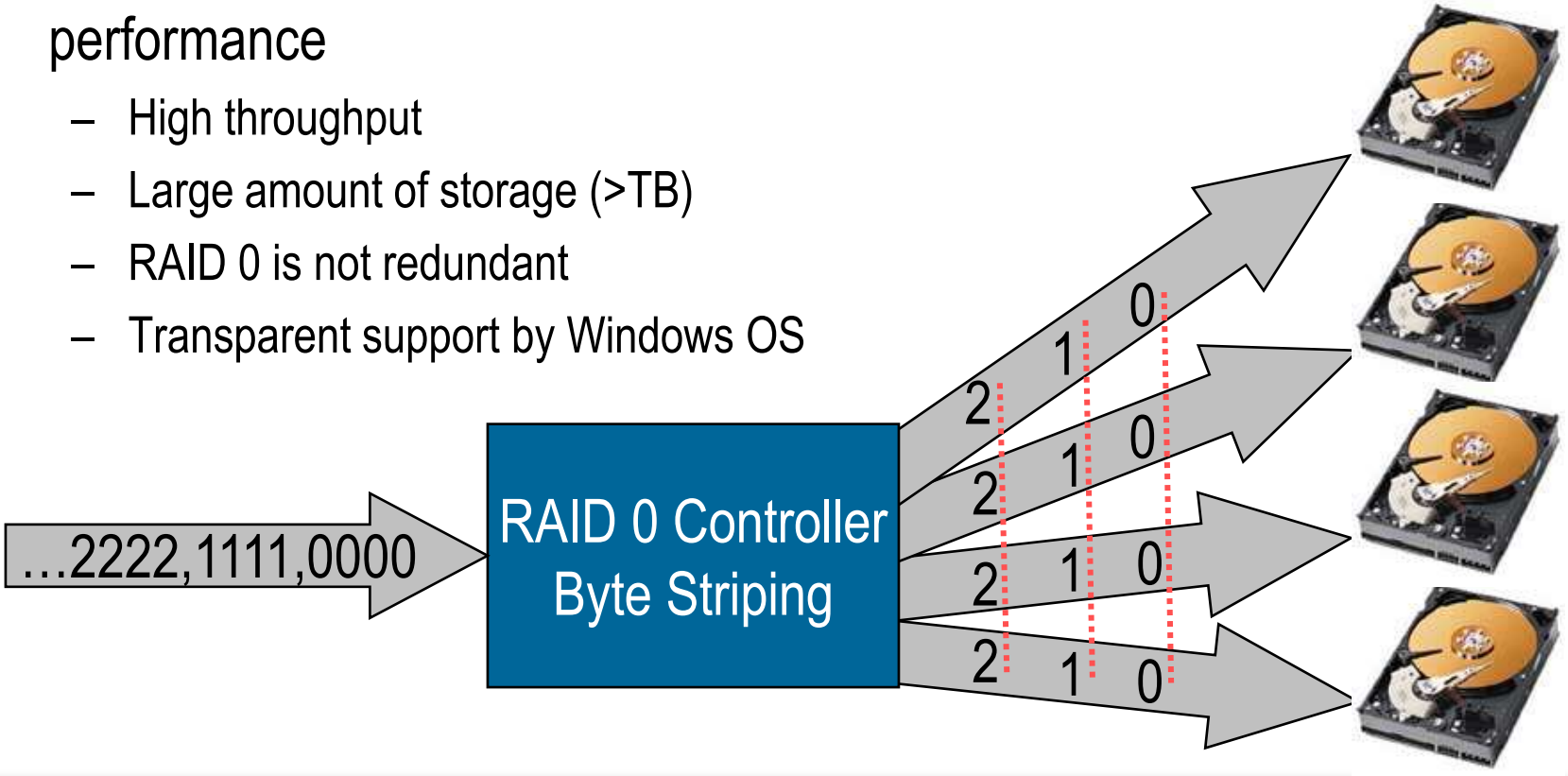


# Technology 1: High-Speed Data Bus



# 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 (>TB)
  - RAID 0 is not redundant
  - Transparent support by Windows OS



# Typical Disk Rates

- GPS (2 MHz) = 10 MB/s
- Broadcast TV (6 MHz) = 35 MB/s
- Spectral Monitoring (20 MHz +) = 100 MB/s +

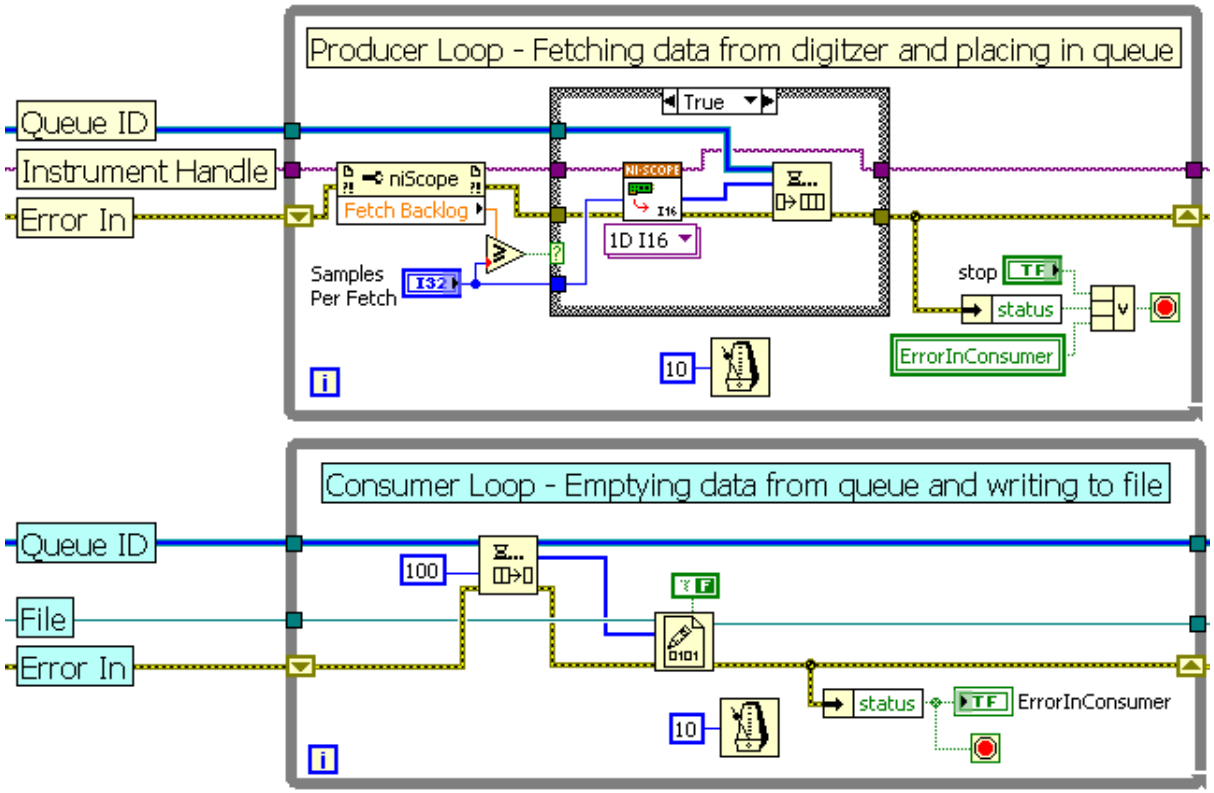
| Drive | Data Rate (MB/s) | Type Size | Details |
|---|---|---|---|
| USB hard disk | 25 | 320 GB | Western Digital passport |
| PXI controller | 30 | 60 GB | NI PXIe-8130 |
| IDE | 55 | 160 GB | Western Digital – 7200 rpm |
| SATA | 75 | 250 GB | Seagate Barracuda – 7200 rpm |
| RAID 0 (4 disks) | 100 | 1 TB | RAID via Express card |
| RAID 0 (4 disks) | 200 | 1 TB | NI HDD-8263 RAID controller |
| RAID 0 (12 disks) | 600 | 3 TB | NI HDD-8264 RAID controller |

# Math Stuff: Signal Bandwidth to Duration

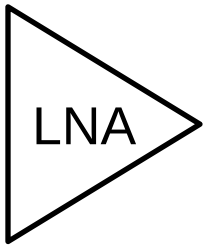
- RF bandwidth = 0.8 x I/Q rate
  - For example, 50 MS/s = **40 MHz** real-time bandwidth
  - Conversion artifact of digital downconversion
- Data rate = 4 bytes per sample x I/Q rate (samples/s)
  - Each sample = 2 bytes for I and 2 bytes for Q
  - 40 MHz = 50 MS/s x 4 = 200 MB/s
- Duration with 2 TB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

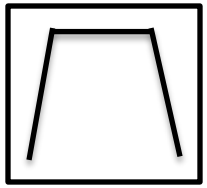
# Technology 3: LabVIEW Multithreading

- Graphical programming simplifies streaming
- A parallel/multithreaded environment optimizes streaming



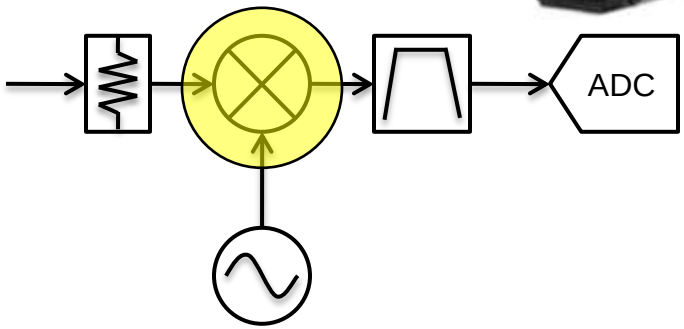
# Configuring the RF Front End for Recording Radiated Signals



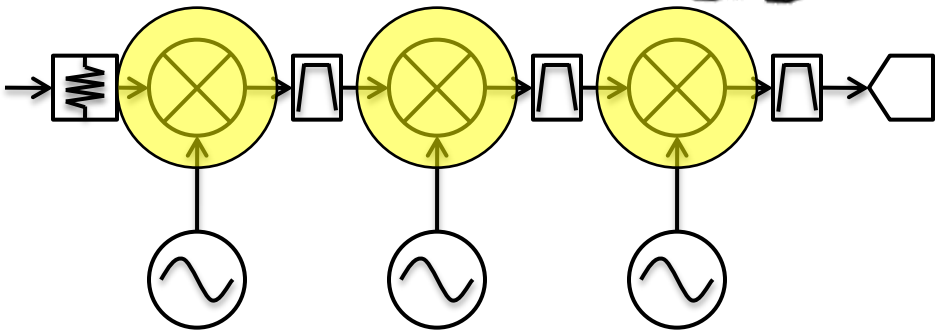
# Single versus Superhet Downconverter

**Single-Stage Downconversion**



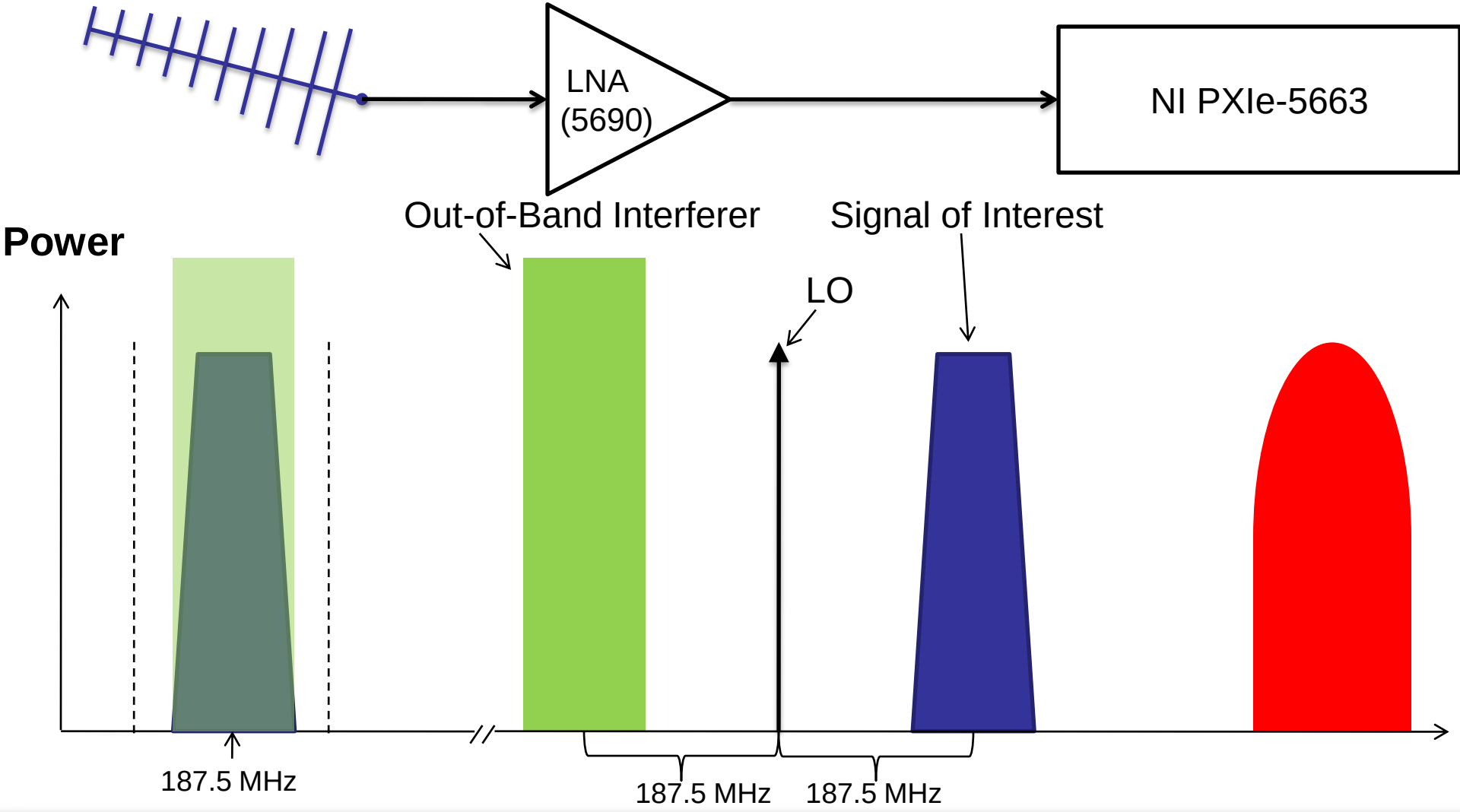

- Example = NI PXIe-5663
- Preselection always recommended
- Better noise floor

**Superheterodyne Downconversion**

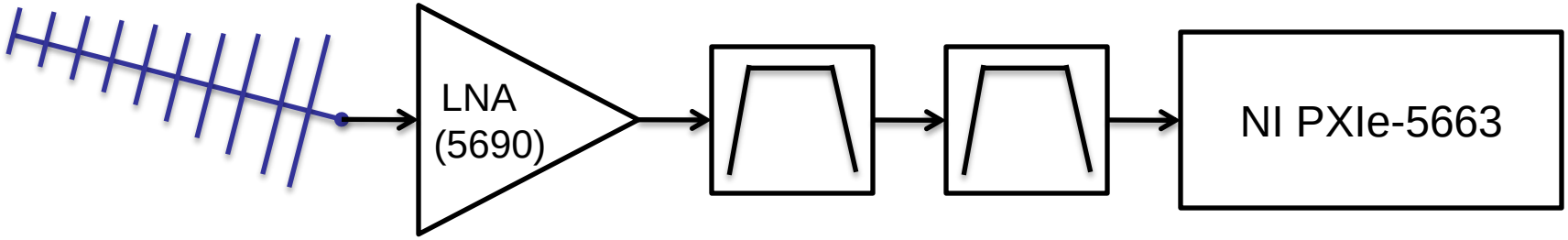


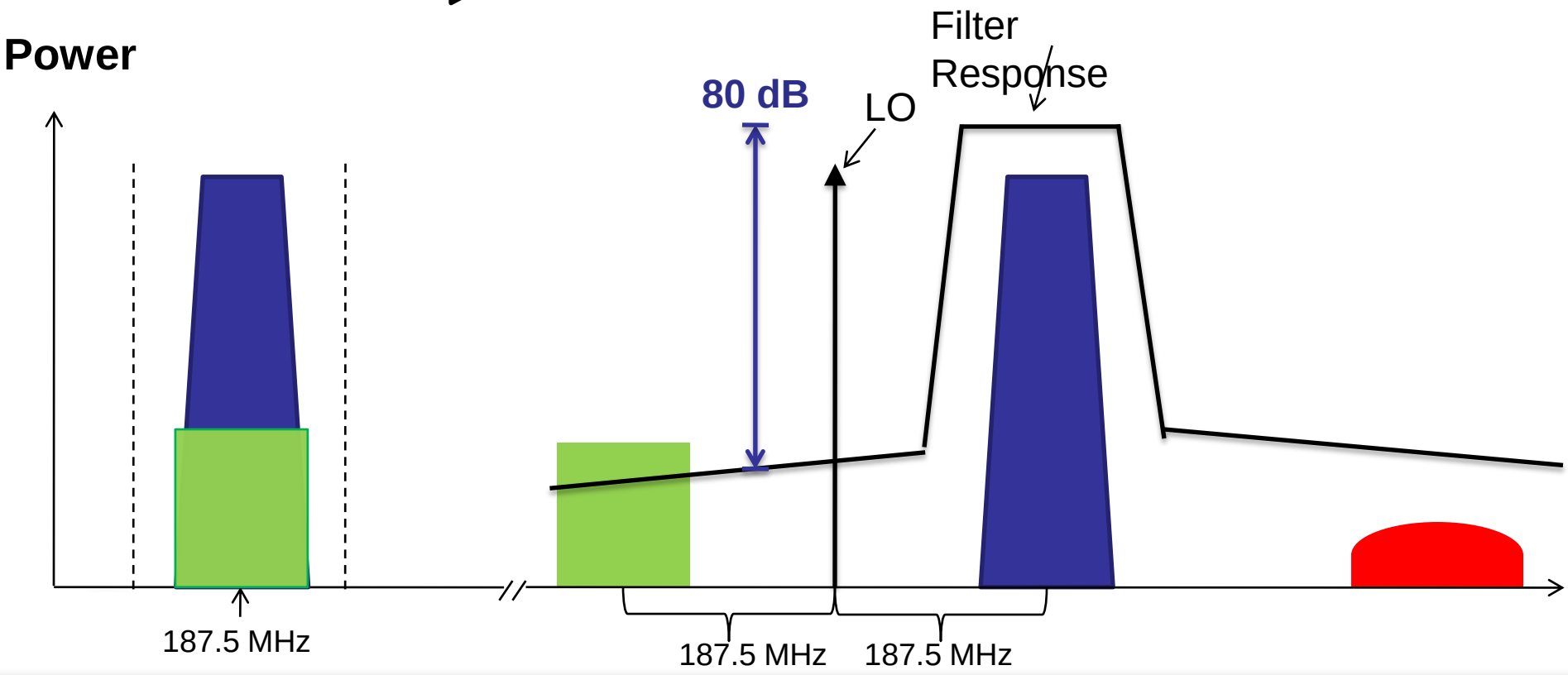
- Example = NI PXI-5661
- Preselection sometimes required
- Better out-of-band and IF rejection

# Single Stage Recording WITHOUT a Preselect Filter

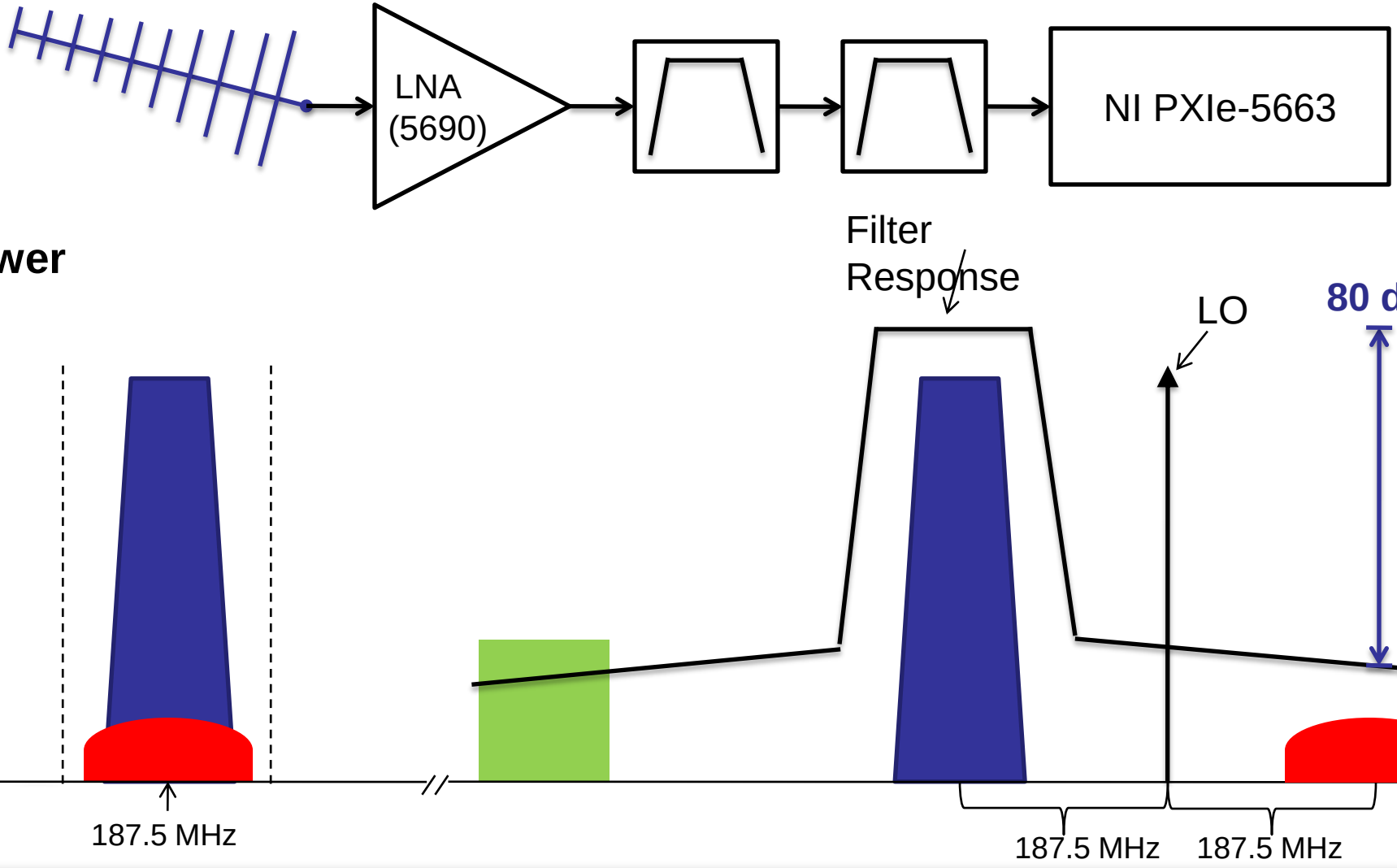


# Recording WITH a Preselect Filter (Low-Side LO injection)



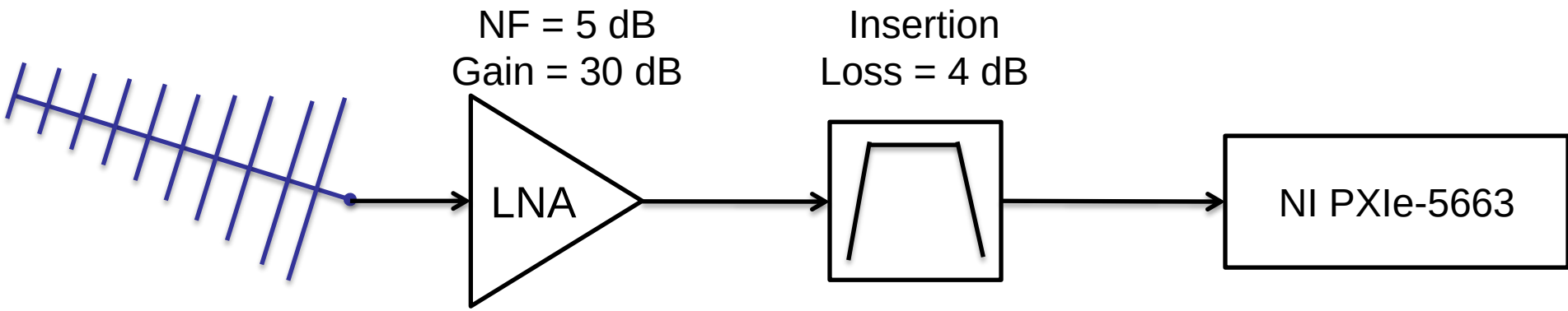



# Choosing LO Injection Side



# Configuring a Preselect Filter

- Filter must be centered at recording signal
- Always place filter after LNA (low-noise amplifier)
  - Filters induce inherent insertion loss
  - Attenuate noise induced by LNA




**SNR = 55 dB**
(noise = -174 dBm/Hz)
(signal = -119 dBm)

**SNR = 50 dB**
(noise = -139 dBm/Hz)
(signal = -89 dBm)

**SNR = 50 dB**
(noise = -143 dBm/Hz)
(signal = -93 dBm)

# Calculating Cascaded Noise Figure

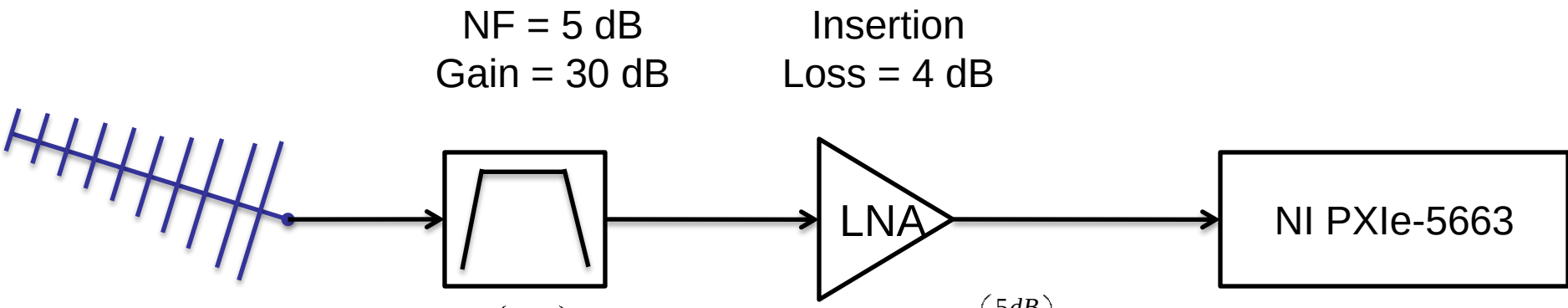
- Amplifiers add noise to any signal – noise figure (NF)
- Filters have noise figure – insertion loss
- NF of a cascaded system can be calculated by:

$$nf_{receiver} = nf_1 + \frac{nf_2 - 1}{g_1} + \frac{nf_3 - 1}{g_1 g_2} + \frac{nf_n - 1}{g_1 g_2 \cdots g_n}$$

$$NF_{dB} = 10 \times \log_{10}(nf) \qquad nf = 10^{\left(\frac{NF_{dB}}{10}\right)}$$

*NF* = Noise figure
*nf* = Noise factor
g = Gain (linear)

# Scenario 1: Filter Before LNA



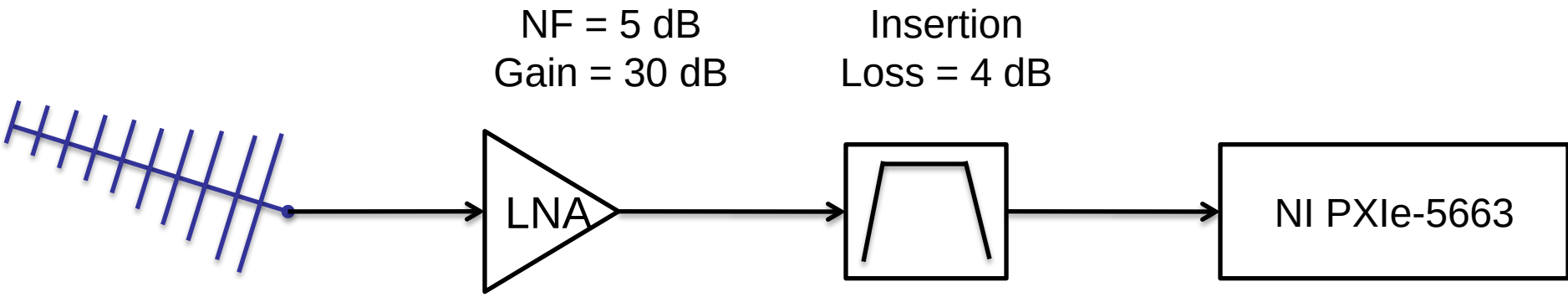

$$nf_{filter} = 10^{\left(\frac{4dB}{10}\right)} = 2.51 \qquad nf_{LNA} = 10^{\left(\frac{5dB}{10}\right)} = 3.16$$

$$g_{filter} = 10^{\left(\frac{-4dB}{10}\right)} = 0.4 \qquad g_{LNA} = 10^{\left(\frac{30dB}{10}\right)} = 1000$$

$$nf_{receiver} = nf_1 + \frac{nf_2 - 1}{g_1} = 2.51 + \frac{3.16 - 1}{0.40} = 2.51 + 5.40 = 7.91$$

$$NF_{dB} = 10 \times \log_{10} 7.91 = 9.0$$

# Scenario 2: LNA Before Filter



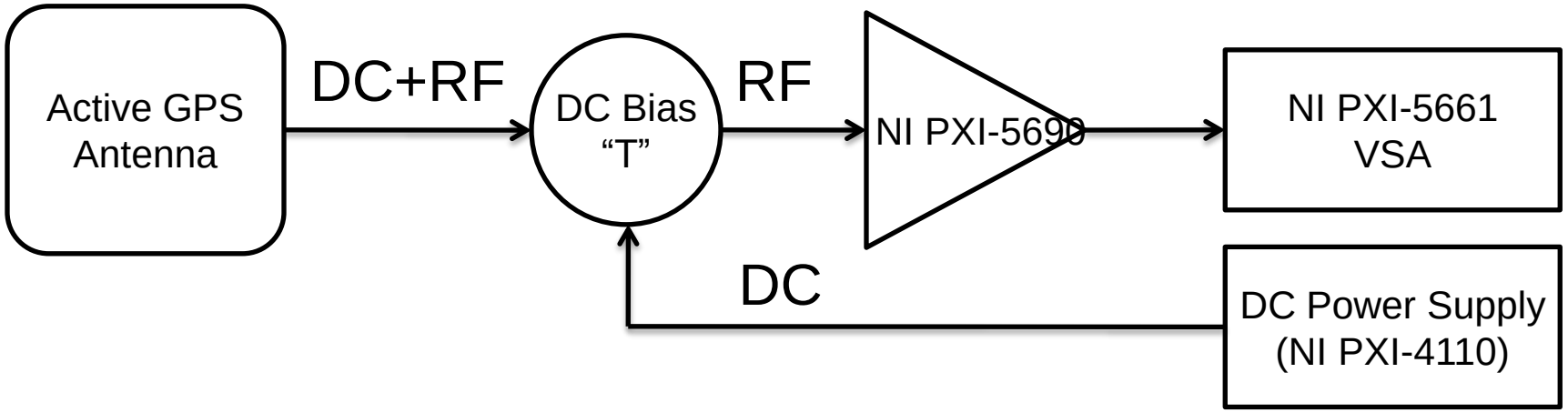

$$nf_{LNA} = 10^{\left(\frac{5dB}{10}\right)} = 3.16 \qquad nf_{filter} = 10^{\left(\frac{4dB}{10}\right)} = 2.51$$

$$g_{LNA} = 10^{\left(\frac{30dB}{10}\right)} = 1000 \qquad g_{filter} = 10^{\left(\frac{-4dB}{10}\right)} = 0.4$$

$$nf_{receiver} = nf_1 + \frac{nf_2 - 1}{g_1} = 3.16 + \frac{2.51 - 1}{1000} = 3.16 + 0.00151 = 3.16$$

$$NF_{dB} = 10 \times \log_{10} 3.16 = 5.0$$

# Using Active Antennas – GPS



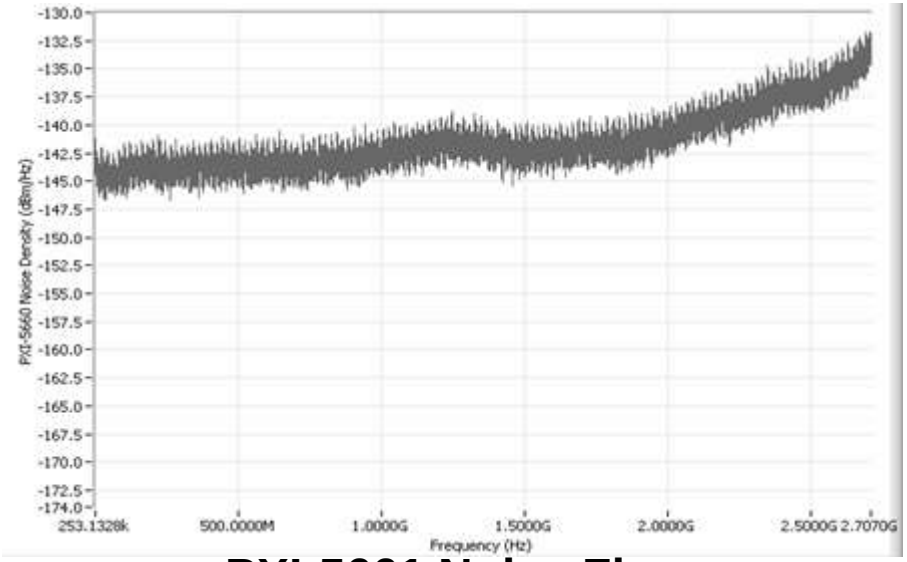

| Stage | **Gain (dB)** | **Gain (linear)** | **NF (dB)** | **nf (linear)** |
|---|---|---|---|---|
| Active Antenna | 30 dB | 1000 | 1.5 dB | 1.4125 |
| LNA | 30 dB | 1000 | 5 dB | 3.1623 |

$$nf_{receiver} = 1.4125 + \frac{3.1623 - 1}{1000} = 1.4125 + 0.002163 = 1.4147$$

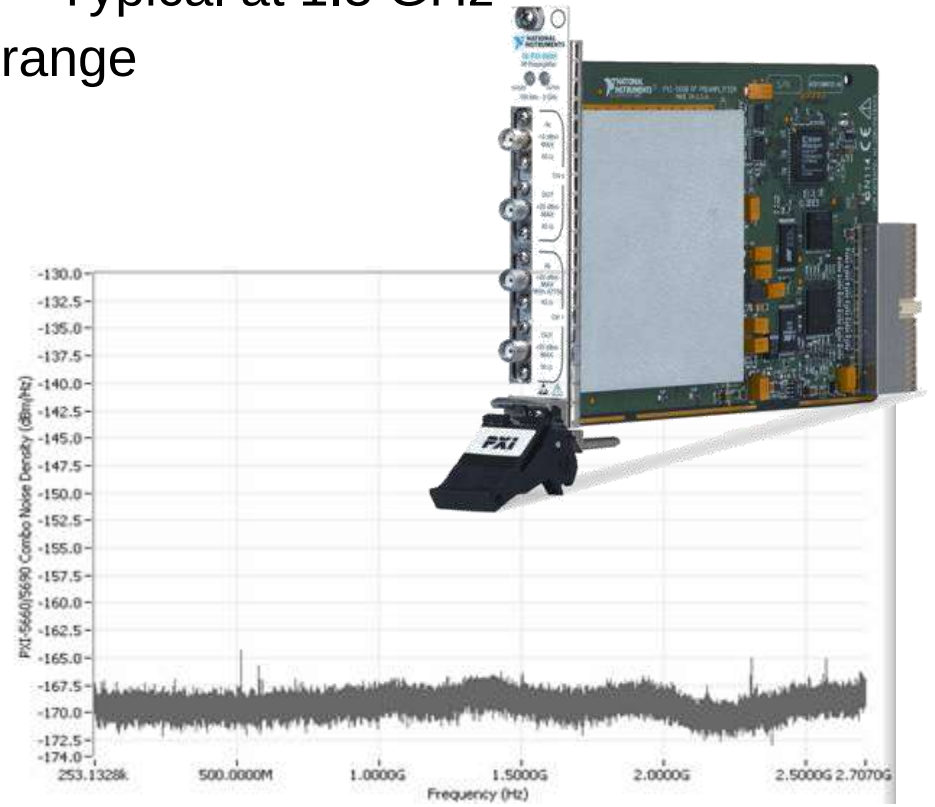
$$NF_{dB} = 10 \times \log_{10}(nf) = 10 \times \log_{10}(1.4147) = 1.507\,dB$$

# NI PXI-5690 RF Preamplifier

- Channel 0:  30 dB gain with 5 dB noise figure – Typical
- Channel 1:  -10 to +20 dB gain – Typical at 1.5 GHz
- 100 kHz to 3.0 GHz frequency range
- Sold separately



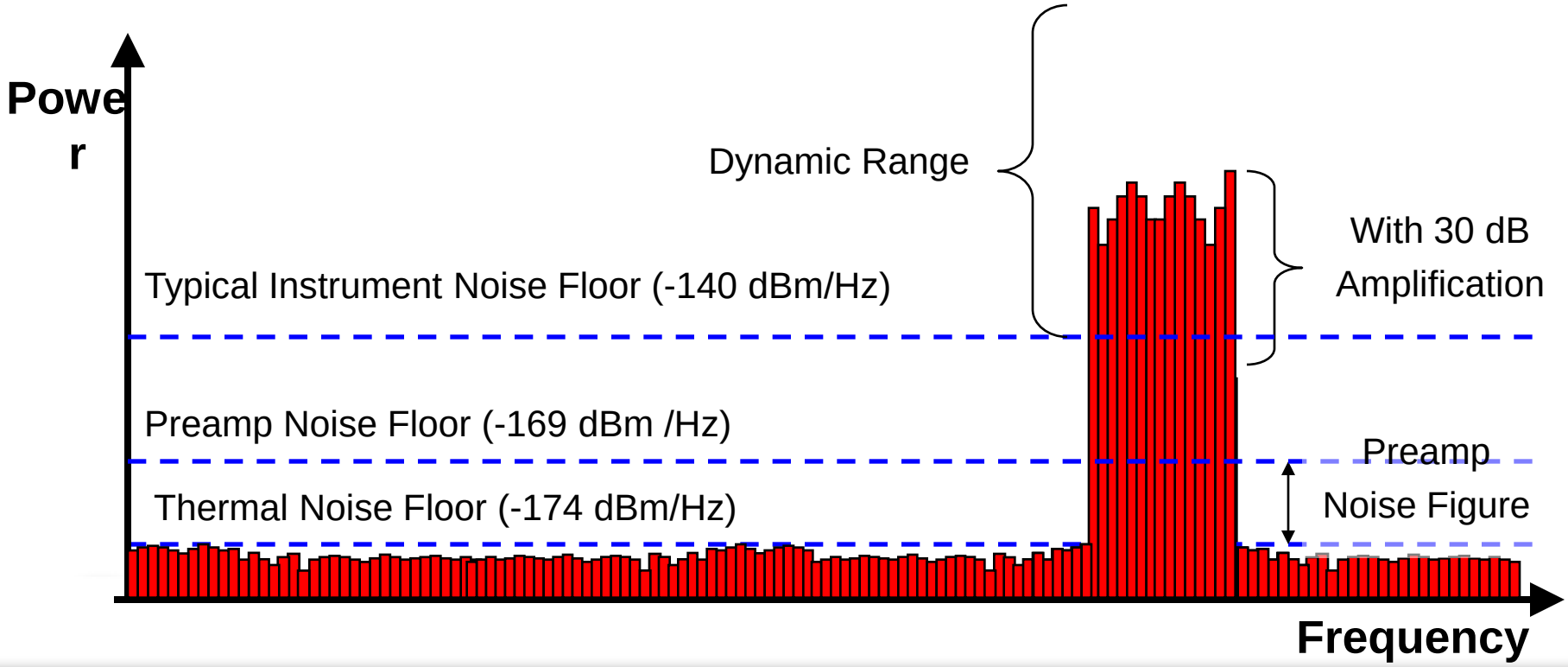

**PXI-5661 Noise Floor**




**PXI-5661 with Preamplifier**

# When to Use a Preamplifier

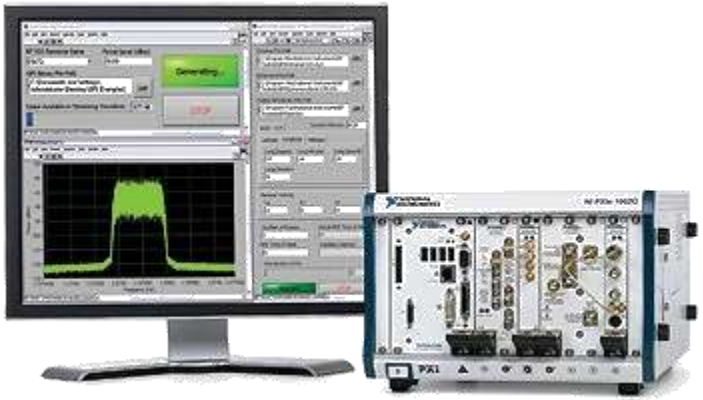
- PXI-5690 noise figure: 5 dB typical to 3 GHz
- PXI-5661/5690 noise floor: -162 dBm/Hz to 2.7 GHz



# Example Application: GPS Receiver Test

- Simulated with LabVIEW
  - Sensitivity and position accuracy testing
  - Single and multiple satellite generation (1 to 12 satellites)
  - Custom latitude, longitude, altitude, and velocity settings
- Record and Playback
  - Ability to capture real-world impairments (multipath fading)
  - Capture dynamic satellite power changes
  - Dynamic receiver position/velocity (drive test)

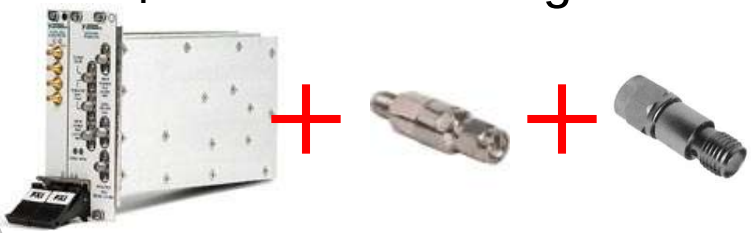
# NI GPS Test Platform



# Options for Receiver Test

## GPS Signal Simulation

- Use NI GPS Toolkit for LabVIEW
- Simulate 1 to 12 satellites in software
- Choose latitude, longitude, and altitude
- Simulate optional receiver movement
- Requires PXI-567x signal



## RF Record and Playback

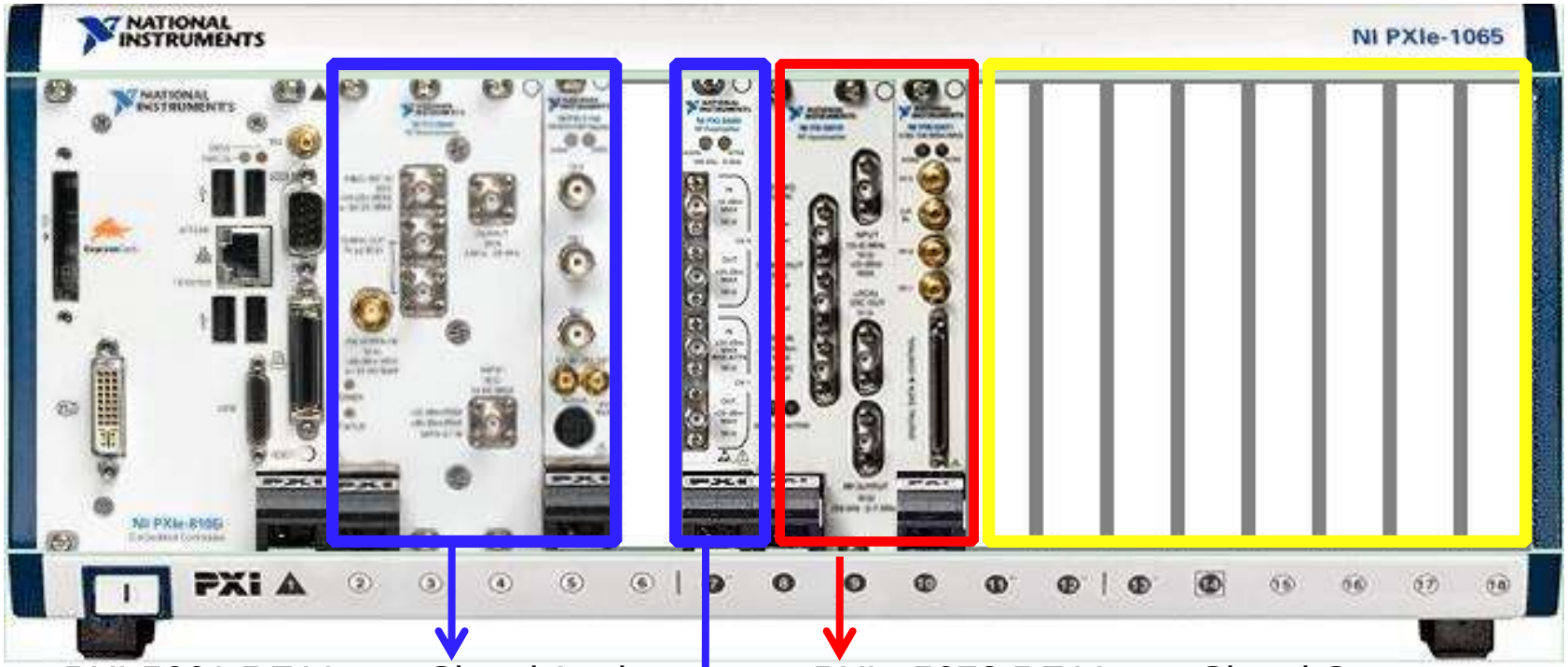
- Use Record and Playback Example
- Used with active GPS antenna
- PXI-5690 pre-amp provides 30 dB gain
- Record with PXI-5661
- Playback with PXI-567x

# Simulated vs. Recorded GPS Generation

- Simulated
  - Better power accuracy (no noise added)
  - Single and multiple satellite generation (1 to 12 satellites)
  - Custom latitude, longitude, altitude, and velocity settings
- Record and Playback
  - Ability to capture real-world impairments (multipath fading, etc.)
  - Capture dynamic satellite power changes
  - Dynamic receiver position/velocity (drive test)

# PXI Express Hardware System

| | |
|---|---|
| Required | Generates GPS signals in L1 band |
| OPTIONAL | Records GPS signals in L1 band |
| EXTENSION | Configure other instruments for additional I/O |




PXI-5661 RF Vector Signal Analyzer

PXIe-5672 RF Vector Signal Generator

PXI-5690 RF Pre-Amp

# Other Recommended Accessories

- DC Blocke
  - Allows connections to DC biased direct connect ports

- Fixed attenuators (pads)
  - Lowers noise performance of generator
  - Reduces VSWR and improves power accuracy
- Active GPS Antenna
  - Used for recording GPS data off tl


- Precision RF power meter
  - Used to calibrate RF power accuracy

# Hardware for RF Record and Playback System

- Record and playback up to 2 TB of data with NI HDD8264
- Use for long-duration signal recording

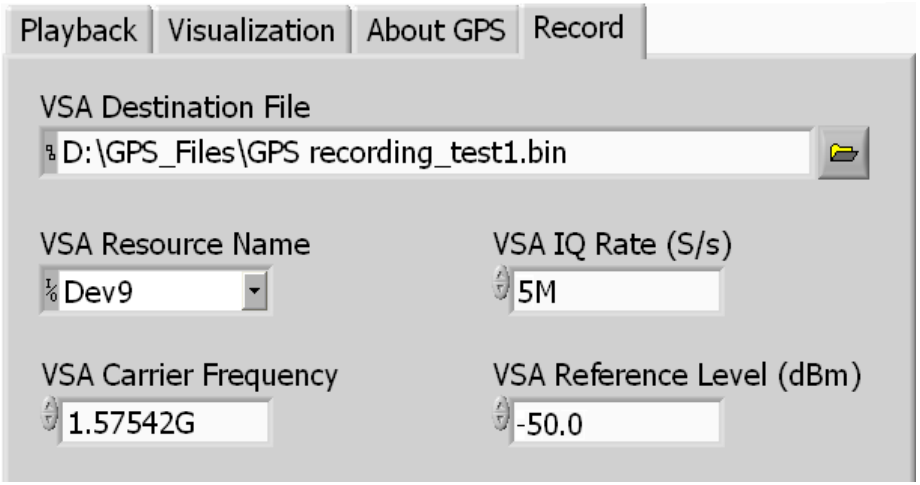
PXIe-5663 ***to disk***

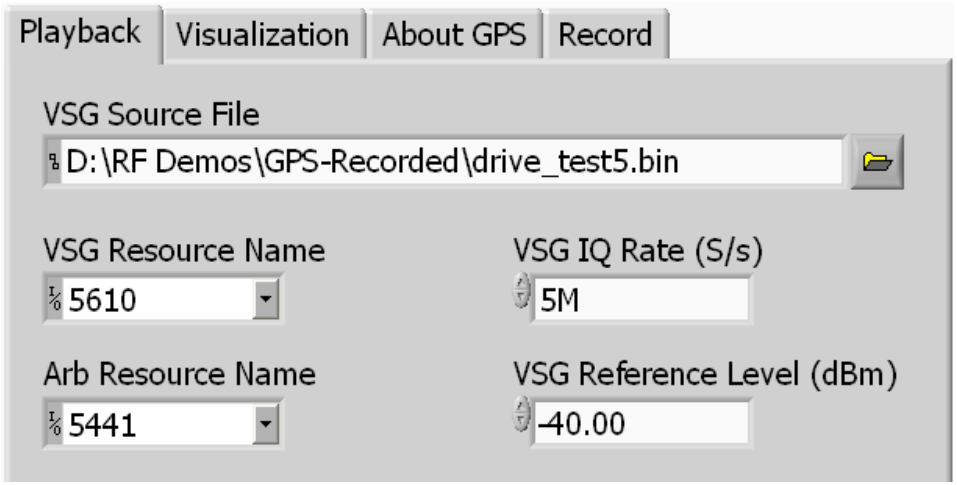
- 50 MHz BW (75 MS/s)
- 300 MB/s
- Record for 1.5+ hours
- May require pre-selection

PXIe-5673 ***from disk***

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

# GPS record and playback



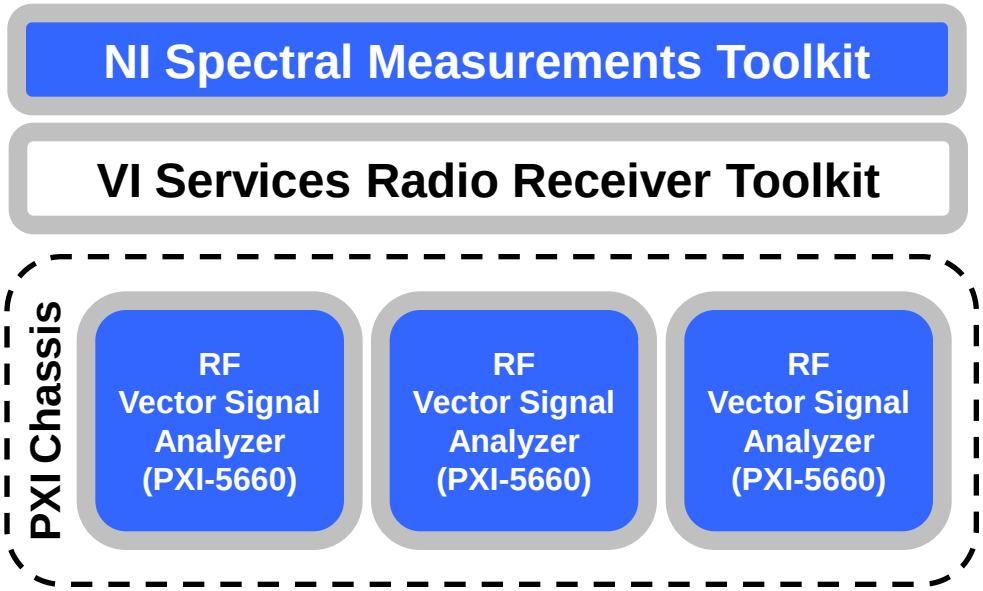




- Record & playback frequency: 1.57542 GHz
- Record reference level: -50 dBm
  - 60 dB of gain should amplify power in L1 band to -56 dBm
- Playback power can be adjusted to achieve C/N target
- For best results, use direct connect with DC blockerh

**Download code at: www.ni/com/streaming/rf**

# Example Application: Chengdu Huari – RF Spectral Monitoring

Image Courtesy of Huari Telecom




***"We significantly improved the functionality and performance of our radio monitor and directional finding systems by using NI RF modules and PXI platform."***
***– Jingyou Mo, President, Huari Telecom***

# Summary

- Stream-to-disk enabled by core technologies
  - High-speed data bus
  - High-speed RAID volumes
  - Parallel LabVIEW programming structure
- RF recording requires special attention to RF front end
- Record and playback enables unique applications
  - Receiver test
  - Spectrum monitoring