NIDays09

WORLDWIDE GRAPHICAL SYSTEM DESIGN

CONFERENCE

NATIONAL INSTRUMENTS

Rookie’s Guide to Sound and Vibration

Agenda

- Why Measure Sound and Vibration
- Acquiring Dynamic Signals
- Noise Vibration and Harshness Application
  - Sound Quality
- Machine Condition Monitoring
  - Order Analysis

Why Measure Sound & Vibration?

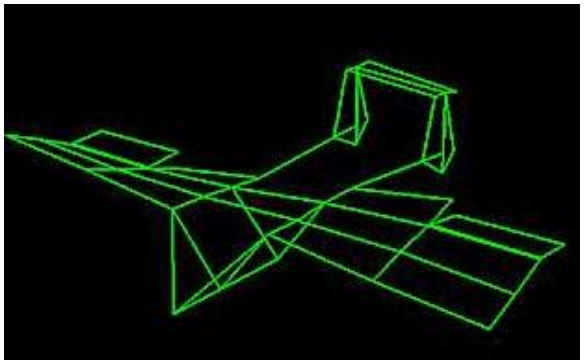
R&D – during research and development, the noise & vibration of a device is studied and attempts are made to reduce its vibration, or improve acoustics thus permitting longer service life and greater appeal to end users. e.g. Appliances, Vehicles, Tools.

Why Measure Sound & Vibration?

Audio Performance – quality of speakers (home/car audio, cell phones), amplifiers, equalizers, etc. characterized by frequency response measurements, distortion analysis, linearity/gain, and even sound quality.

Why Measure Sound & Vibration?

Structural Testing – measuring the vibration response of a structure permits a determination of the integrity of the structure, material properties, and mode shapes. e.g., Fatigue, Stiffness, Cracking.



Why Measure Sound & Vibration?

Control – detect the presence or change of noise or vibration and initiate appropriate action. e.g., Active Suspension Systems, Cabin Noise Suppression, Vibration Shaker Control

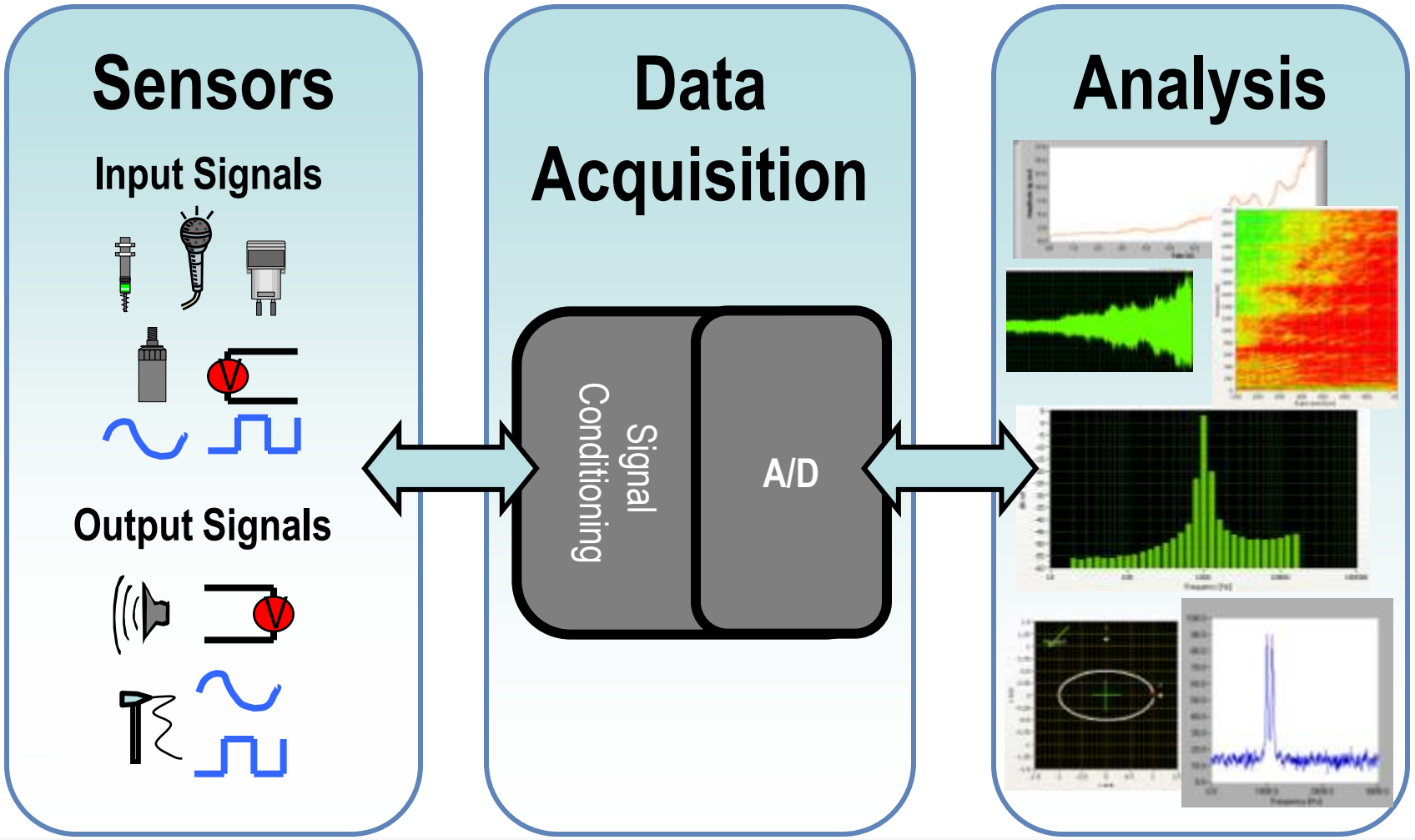
Why Measure Sound & Vibration?

Machinery Protection - monitor vibration and initiate alarm or shutdown when levels exceed a pre-determined threshold.

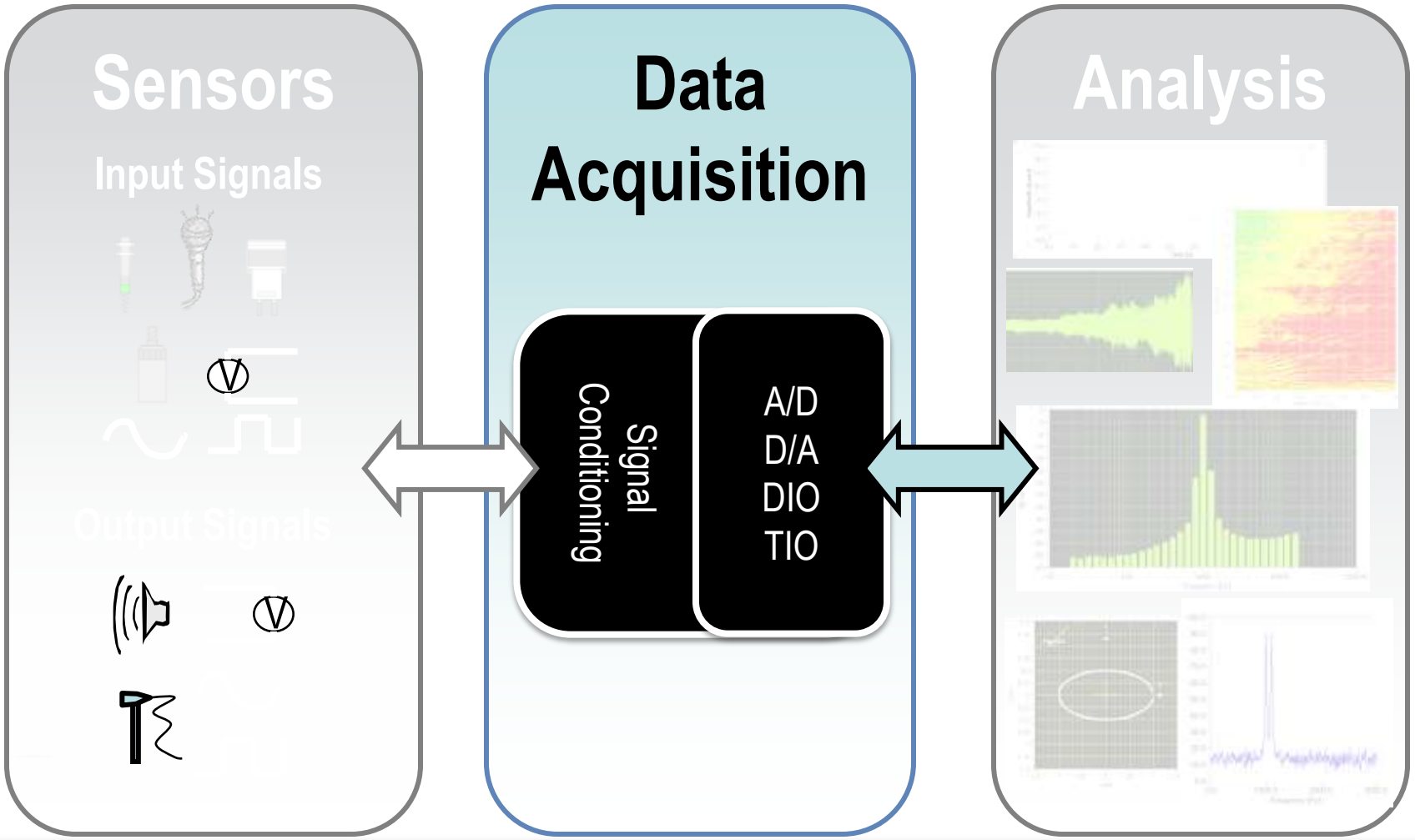
Why Measure Sound & Vibration?

Predictive Maintenance – trend and analyze machinery performance to determine when maintenance will be necessary to avoid a catastrophic failure.

Sound and Vibration Measurement System Components



Measurement System Components

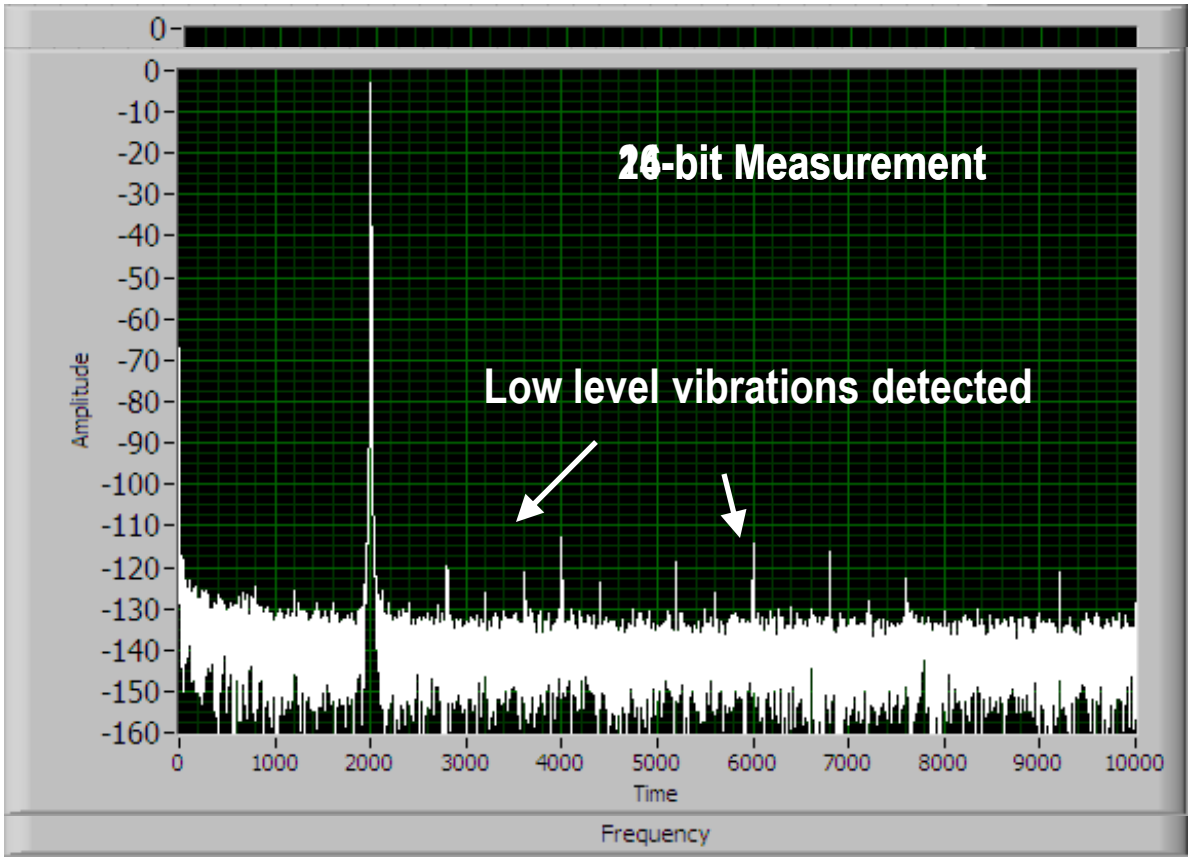


Dynamic Range

High dynamic range allows you to detect both strong and weak signal components at the same time.

90 dB →

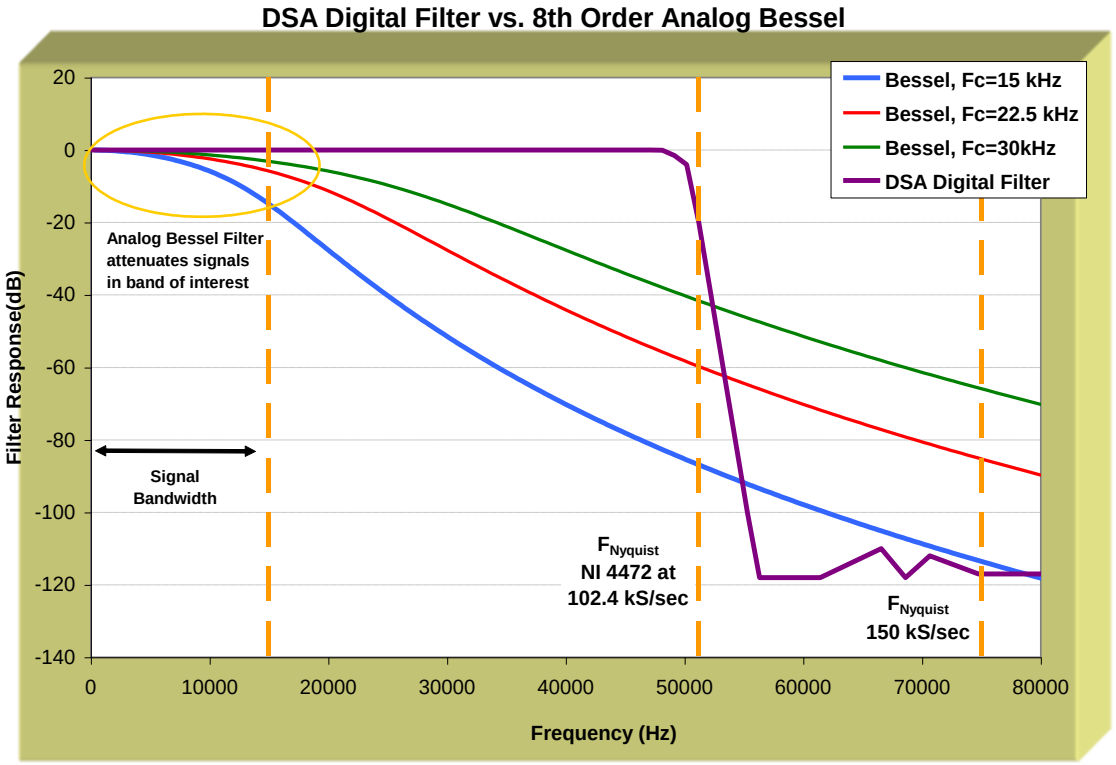
140 dB →



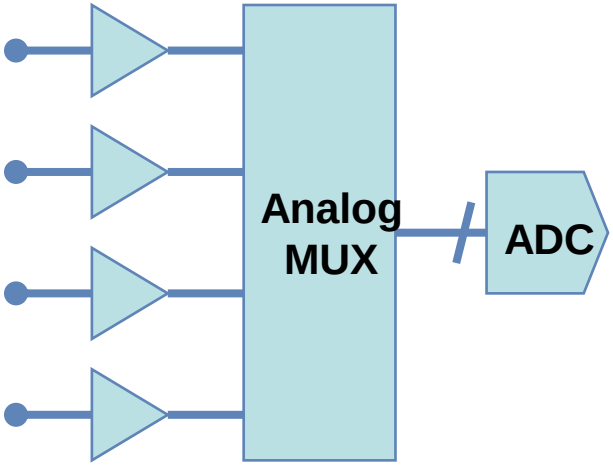
Anti-Aliasing Filter

- Removes frequency components higher than Nyquist frequency
- Needs to be performed before signal is digitized

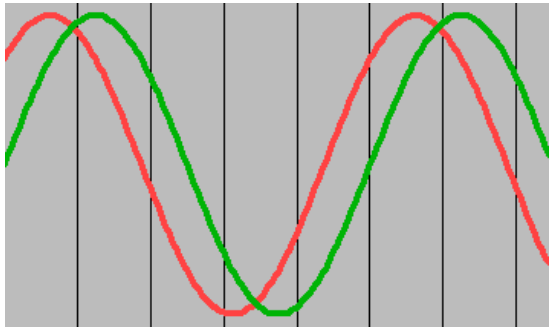
- Mix of analog and digital filters
- Required characteristics:
  - Flat in-band frequency response
  - Good high frequency alias rejection
  - Fast roll-off in the transition band



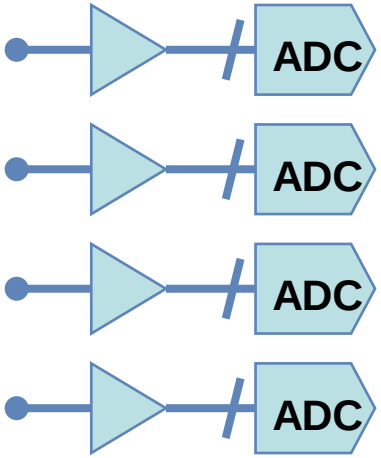
Simultaneous Sampling



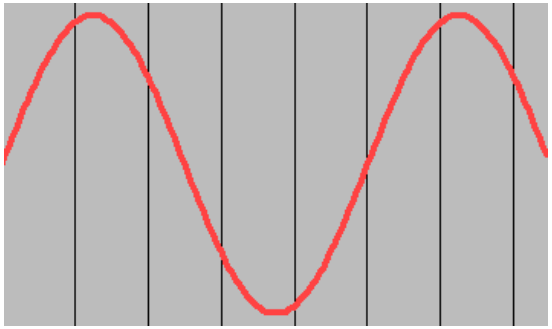
Traditional MIO Device



Multiplexed Architecture
N Channels, 1 ADC
→ **PHASE ERROR**



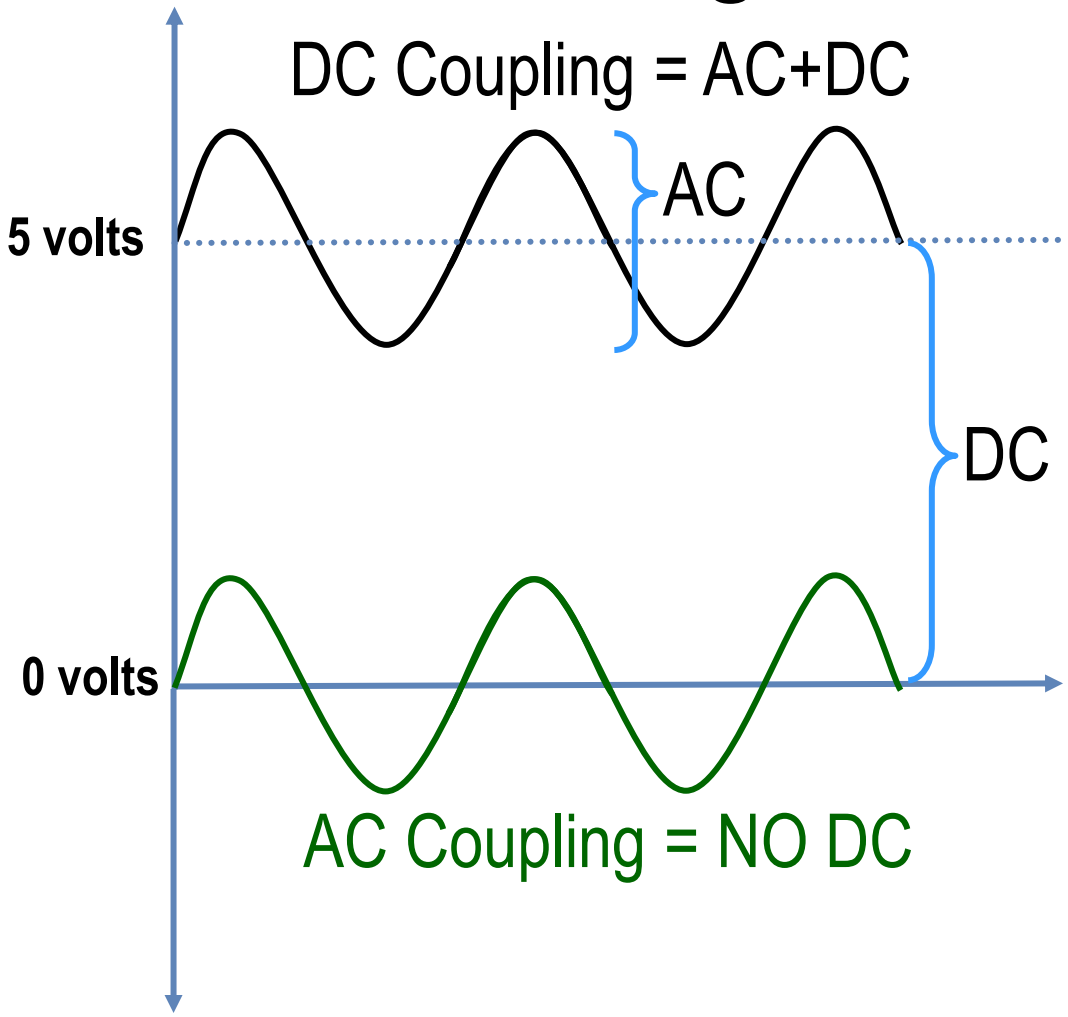
DSA Device



Simultaneous
Architecture
N Channels, N ADCs
→ **NO PHASE ERROR**

Additional Signal Conditioning

- DC and AC Coupling
  - AC Coupling = AC
  - DC Coupling = AC+DC
- IEPE (ICP) = Integrated Electronic Piezoelectric
  - Constant current power supply



National Instruments DSA Products

	Portable	*High Channel Count*		*Performance*
Max Samp Rate	51.2 - 202.4 kS/s	102.4 kS/s	204.8 kS/s	204.8 kS/s
Dynamic Range	102 dB	101-110 dB	113 dB	118 dB
Models	C-Series 9234 USB-443x	PXI/PCI-447x	PXI-449x PXIe-449x	PXI/PCI-446x
				

Noise Vibration Harshness

Microphones

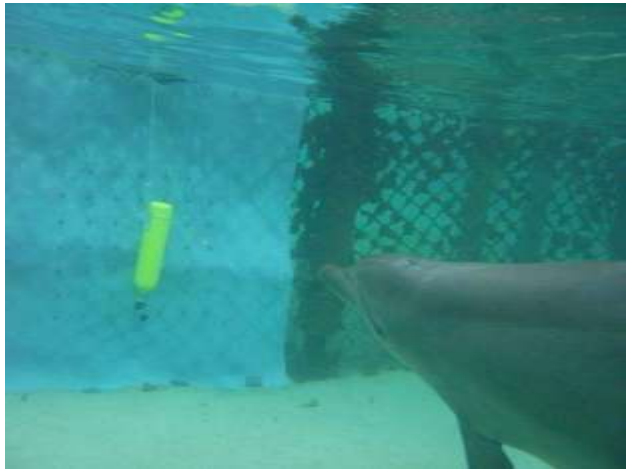
- Measure Sound Pressure Level (SPL)
  - a variation around the atmospheric pressure
- Result is expressed in dB (ref 20 μPa)
  - SPL = 20 $\log_{10}(p/p_0)$ with p_0=20 μPa
  - Typical levels: 30 dB (whisper) to 120 dB (pain)
  - Audible frequency range: 20 Hz to 20 kHz
- Calibration with a reference noise source (94 dB typical)

Microphone Applications

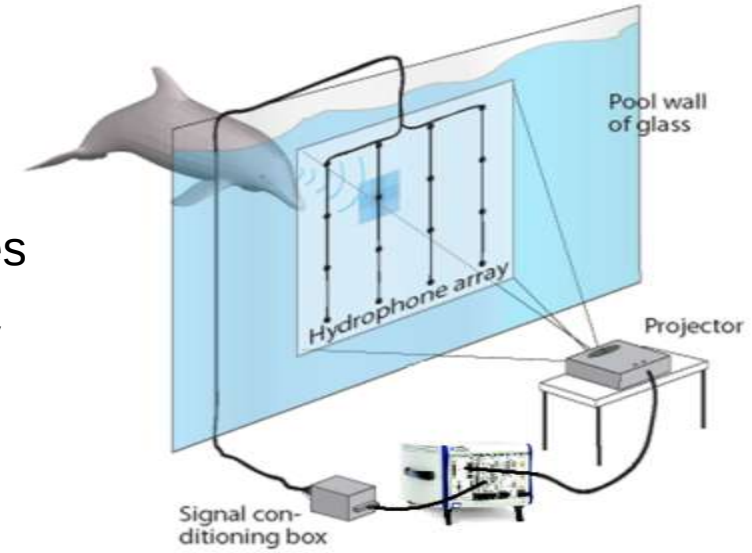
- Acoustic array
- Sound quality
- Sound power
- Pass-by-noise

Example– The Dolphin sonar project

- ELVIS II
  Echo Location Visualization Interface System
- Lund University in collaboration with Kolmården wild animal park
- PhD Student Josefin Starkhammar as developer
- LabVIEW and 47 channel PXI system for digitizing and visualizing dolphin sonar

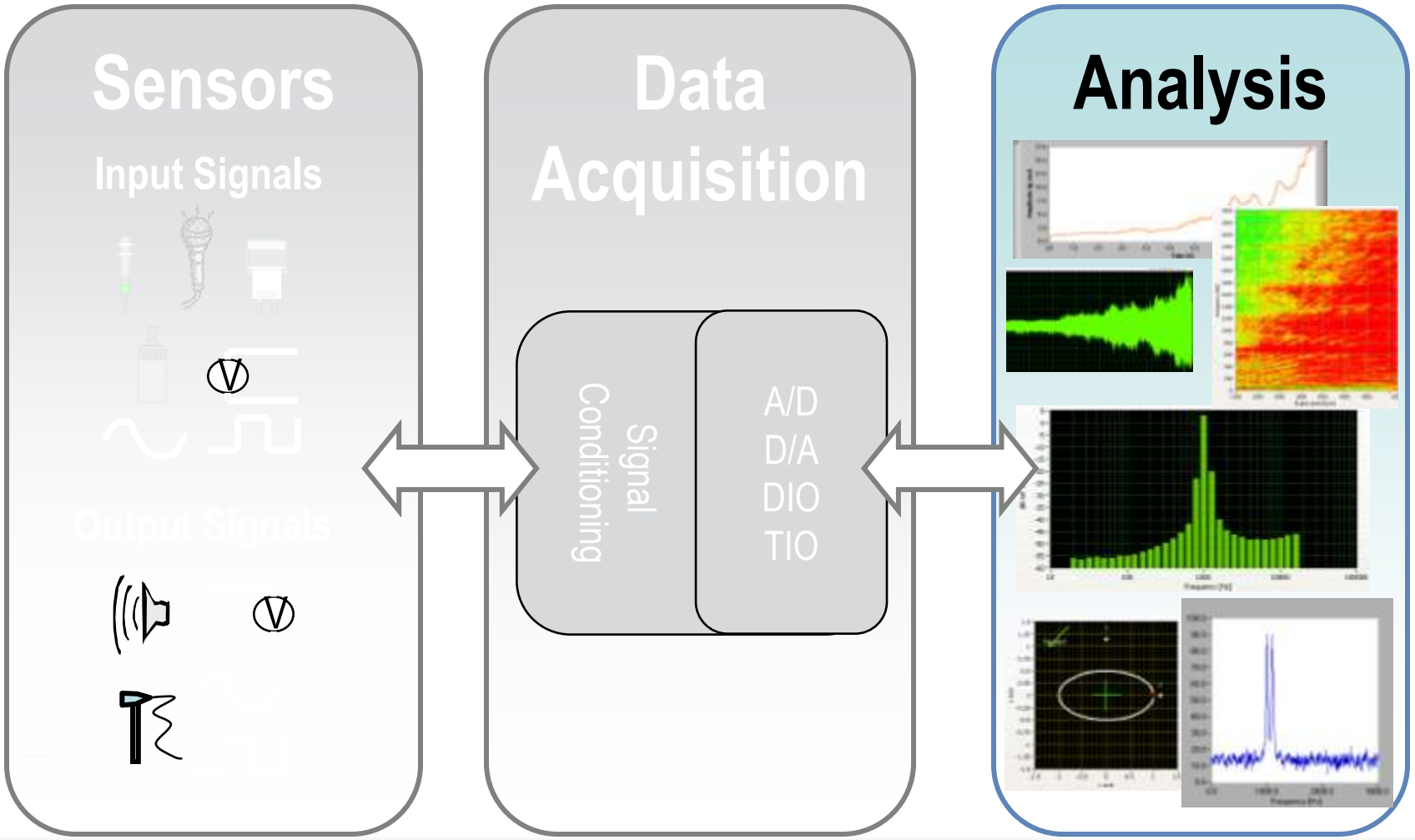


System Principle



- 47 simultaneously sampling hydrophones
- Triggers on arbitary hydrophone in array
- Fast ”re-arm” time
- Fast data streaming to disc
- Real time (or close to real time) visualization of measurements
    - Allows to develop an acoustically operating touch screen

Measurement System Components



What is Sound Quality?

- Sound Quality is focused on
  - understanding how sounds are perceived
  - relating subjective response to objective metrics
  - modifying the device or process accordingly
- Sound Quality is typically applied to commercial products
  - Automobiles, Computers, Appliances….

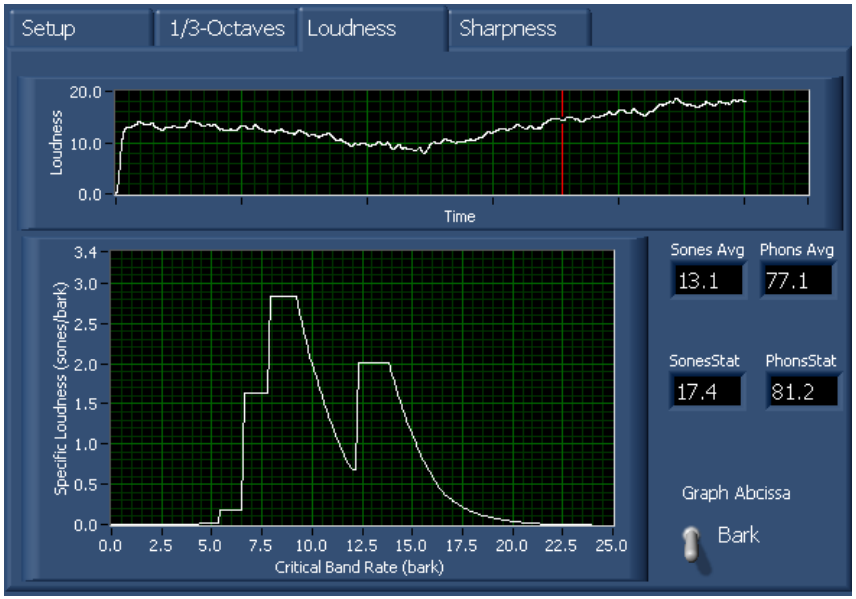
What's "Wrong" with the Rest of Acoustics?

- Human perception is only one aspect of acoustics
- Some acoustic analysis methods are geared towards human perception:
  - Proportional band (octave) analysis
  - Decibel levels
  - A-weighting
- Yet they miss many important phenomena
- Sophisticated "psychoacoustic" tools are needed……

Give Me an Example….

Masking refers to the ability of one sound to be obscured by another.

Thus the perceived loudness of a sound cannot always be determined from its energy (“sound quantity”)



Sound Quality Toolset

- Implement the most common SQ metrics in LabVIEW
  - Loudness
    - Stationary, time-varying, various flavors…
  - Sharpness (relative high frequency content)
  - Roughness (fast modulations)
  - Fluctuation Strength (slow modulations)
  - Tonality (relative proportion of tonal energy)
- Drawn from German psychoacoustics literature

Loudness (Zwicker, ISO 532B)

- Loudness is expressed in “sones”
  - 1 sone has loudness of a 40 dB 1 kHz tone
  - A linear value, 2 sones are twice as loud as 1
- Loudness Level in “phons”
  - X phon has the loudness of an X dB 1 kHz tone
- ISO532B.vi
  - consumes a 1/3 octave band spectrum
  - provides loudness, loudness level, specific loudness

Testing Wind Turbines for Noise Emissions

- Standardized test system to measure the noise impact of wind turbines to comply with the International Electrotechnical Commission (IEC) and other standards
- Custom measurement system that uses the NI PXI dynamic signal acquisition modules to measure acoustic data from microphones and offers advanced measurement and analysis developed using LabVIEW

USB 443x (NEW!)

- 24-bit , 102.4 kS/sec sampling ($500 / channel)
- 4 simultaneous inputs, ±40V input range (±60V max without damage)
- 24-bit DAC analog output (4431), or 5th analog input for tachometer (4432)
- 101 dB dynamic range
- Software-selectable AC/DC coupling
- Software-selectable IEPE excitation (2.1 mA)
- 0.1 Hz AC cutoff high-pass filter
- TEDS support (IEEE 1451.4)
- USB bus-powered

113 dB dynamic range, 204.8 kS/s

449x Family

- 24-bit, 204.8 kS/sec sampling
- **16 simultaneous inputs**
- 113 dB dynamic range
- **10, 20, 30 dB gains correspond to** ± 0.316V, 1V, 3.16V, & 10V input ranges
- Anti-aliasing filters
- **TEDS support (IEEE 1451.4)**
- Software-configurable IEPE (4 mA)
- 0.5 Hz AC cutoff high-pass filter
- Always AC-coupled (NI 4496, NI 4498)
  - DC-coupled version (4495) available
- PXI or PXIe

PXI/PCI 446x series

- Six gain settings for input ranges from ±316 mV to 42.4 V
- Four simultaneously sampled analog inputs at up to 204.8 kS/s
- Software-configurable AC/DC coupling and IEPE conditioning
- Variable antialiasing filters
- Support for IEEE 1451.4 Class 1 Smart (TEDS) Sensors
- 24-bit resolution ADCs with 118 dB dynamic range

Sound Quality Demo

- In Email

Conclusion Sound Quality

- Sound Quality is more complex than conventional acoustical analysis
- Computations are (for the most part) not standardized
- Algorithms have traditionally been proprietary
- Sound Quality Toolset implements key metrics in LabVIEW

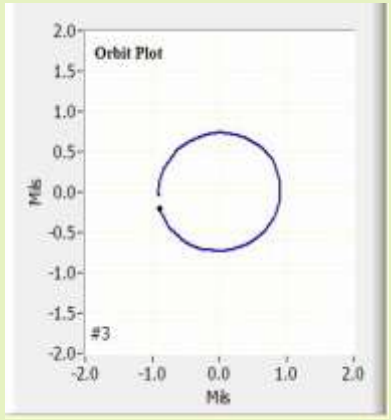
MCM

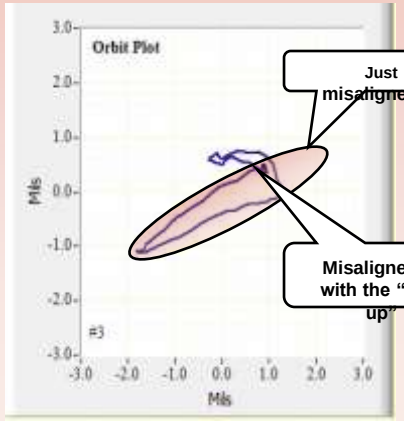
Order Analysis

- Used for mechanical systems with **rotating / reciprocating** components:
  - Engines, gearboxes, transmissions, motors, rotors, turbines, pumps, compressors
- Many noise and vibration signal components are directly related to running (**rotational / reciprocating**) speed:
  - Imbalance, misalignment, gear mesh, bearing defects, loose coupling
- Order analysis normalizes the measurements to the **rotational / reciprocating** speed to better dissect these signal components

Orbit Plot

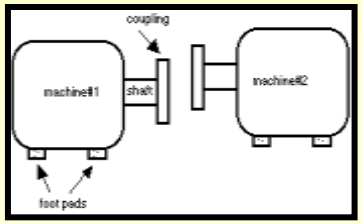
“Normal” Orbit

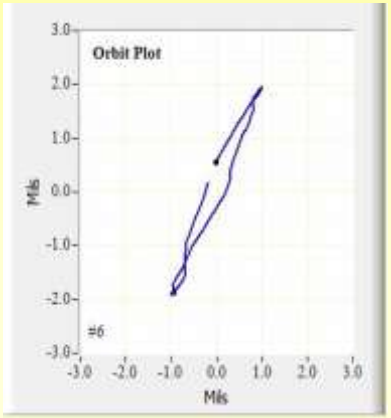


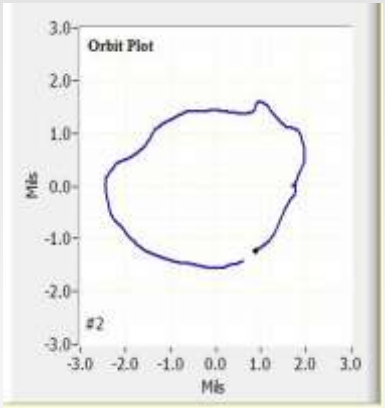


“Locked up” Coupling

Severe Shaft Misalignment

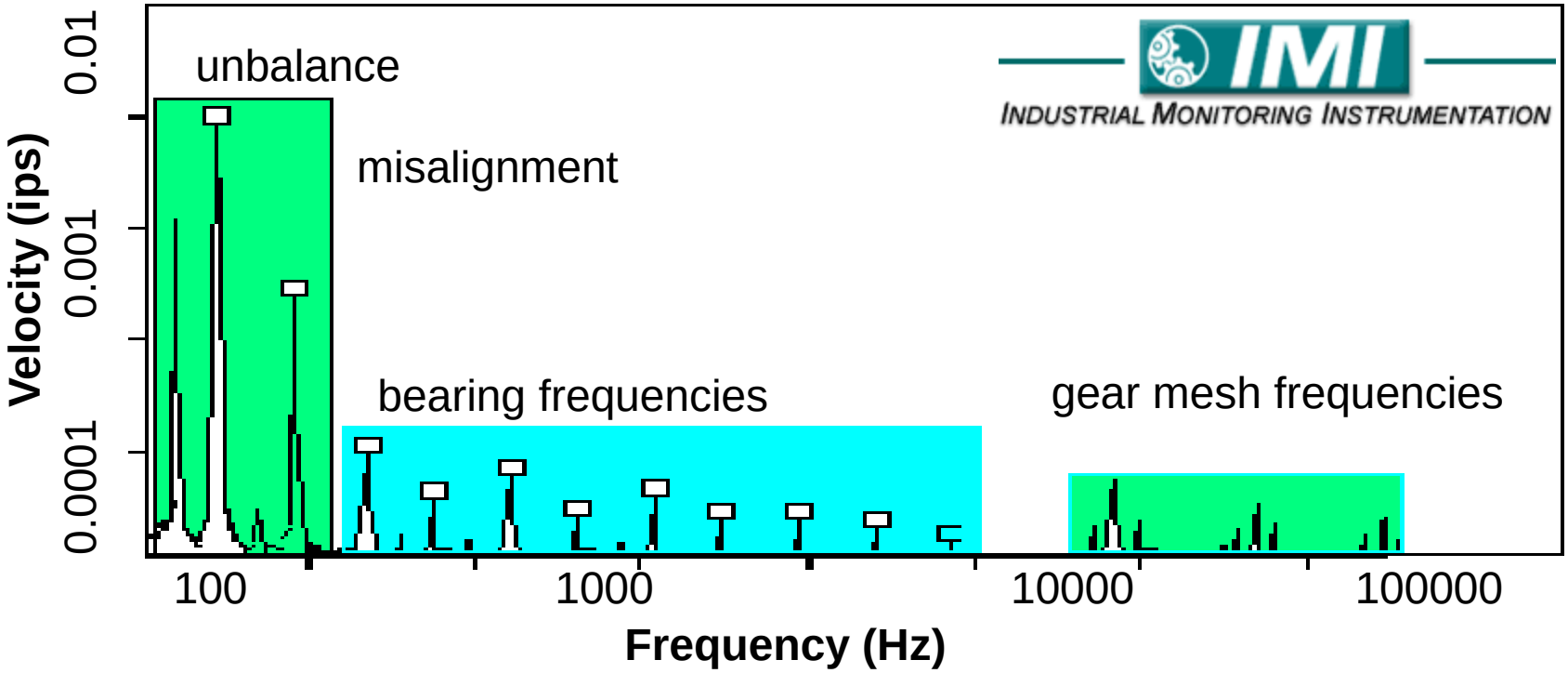






Unbalance

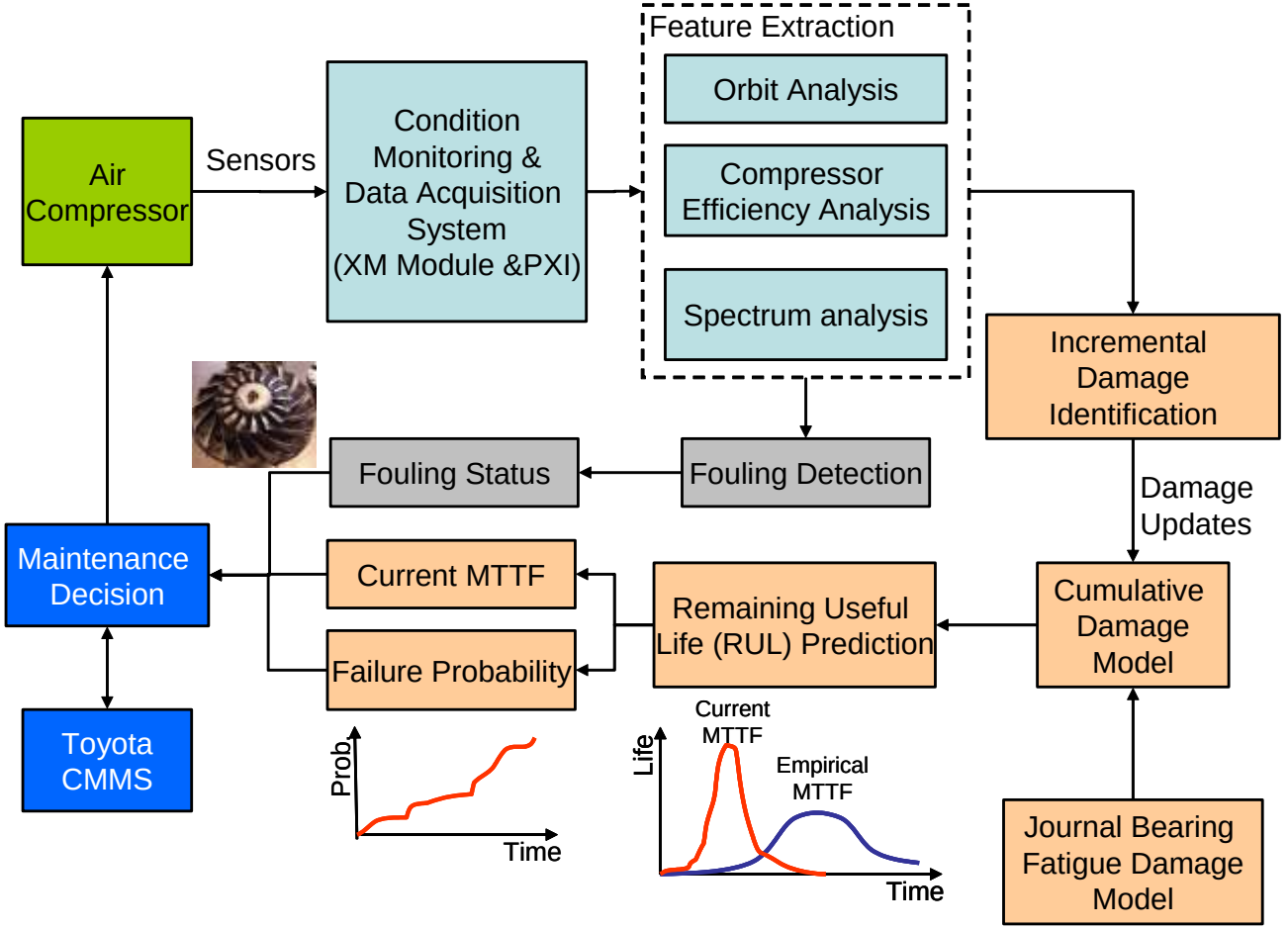
Typical Spectrum Showing Basic Faults



Challenges in Implementing an Intelligent Maintenance System

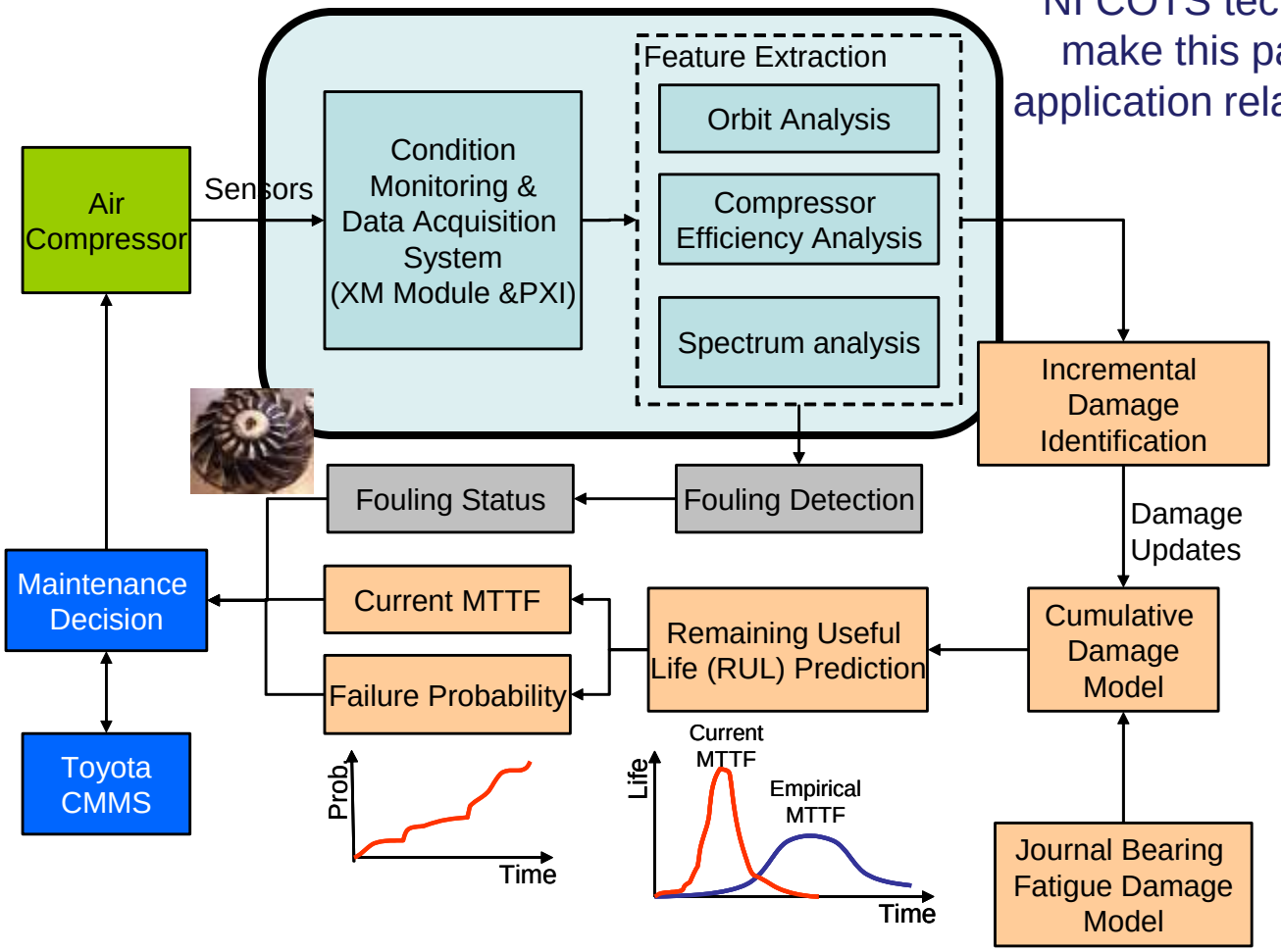
- Identify critical systems and failure modes (motor, gearbox, cables, etc.)
- Acquire relevant sensor data from machines and subsystems of interest
- Use data analysis algorithms and data mining technologies to extract key performance metrics and correlate them with degradation and failures
- Implement decision support based on measurement and CMMS data

Bearing Prognostics



Bearing Prognostics

NI COTS technologies make this part of the application relatively easy



9234 Family

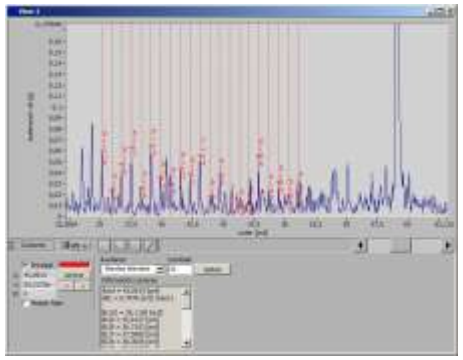
- **Specifications**
  - 4 simultaneous inputs ($450 / channel)
  - 24-bit, 51.2 kS/sec sampling
  - 102 dB dynamic range
  - +/- 5V input range
- **Signal conditioning**
  - AC/DC Coupling & 2 mA IEPE excitation
  - 0.5 Hz AC cutoff high-pass filter
  - Continuously variable anti-aliasing filters
  - TEDS support (IEEE 1451.4)

Order Analysis Demo

- CompactDAQ with NI-9234
- Wireless 9234 if available doing order analysis/Timebase and Polar Plot with Sound and Vibration Demo Box

Condition Monitoring in Open-Pit Mining Electromechanical Shovels

CompactRIO measures vibration and compares to alarm limits



Analysis software is fully built in LabVIEW.

Mining electromechanical shovels can load 100 ton of ore per pass. Combined rated power is about 3MW. Hardware must survive in a harsh environment.

Bearing Monitoring

FAG Industrial Services

- Custom analysis algorithm on FPGA
- Real-Time System for managing analysis and communication
- Host application For Control & asset management

Digital Demodulation online