

Advanced Wireless Architectures for Synchronizing Dynamic Measurements with GPS Technology

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GPS synchronization enables synchronized measurements over extremely large areas. GPS provides a method of sharing timing signals without the need to run timing cables to each measurement system. Another benefit to GPS is that your data is always time stamped to a global time standard which allows you to associate your data with data sets from other systems which are also synchronized to GPS with a high level of confidence. Some applications which can take advantage of the benefits of GPS that require dynamic signal acquisition include structural monitoring, electrical power grid monitoring, ground vibration monitoring and noise and acoustic imaging.

Agenda

- Timing Signals in Dynamic Signal Analysis (DSA)
- Signal-based Synchronization
- GPS Time-based Synchronization (Wireless)
- Synchronization Results
- Advanced Wireless Applications

It can be very useful to correlate data acquired from different systems particularly dynamic signals from accelerometers or microphones simultaneously while maintaining the phase and amplitude relationships with precise timing. Synchronizing input from a large microphone array is a matter of routing the right clocks and triggers across the proper pathways.

High channel count as well as large size of the units under test, provides challenges in synchronization to maintain these phase relationships. Signal based time refers to unit-less ticks or events that mark an instance in time. These are often electrical signals, such as a voltage transition. It is a well developed technology and depends on auto routing of which clocks and triggers to use to auto synchronize multiple identical devices.

Signal based synchronization of a microphone array that maintains a phase relationship of less than 0.3 degrees of phase mismatch in the worst case has been achieved in a 2D array of 100 m. by 100 m. This was done via a distributed architecture by sharing sample clock and triggers via coaxial cable and driver software to route these signals.

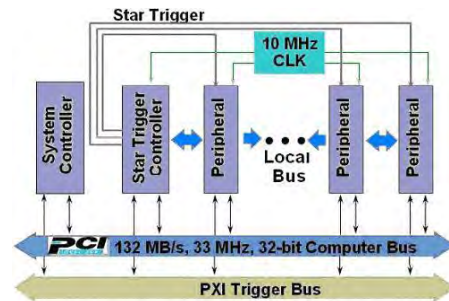
Time based synchronization is in its infancy. Time based synchronization refers to the use of time with units to coordinate and control different systems. Time based synchronization via GPS, IEEE-1588 or IRIG-B requires no direct connection and achieve good results over much longer distances.

Timing Signals for DSA

- Sync Pulse
 - Resets internal counters and ADCs
- Start Trigger
 - Starts acquisition
- 10 MHz Reference Clock
 - Used as reference clock by internal sample clock

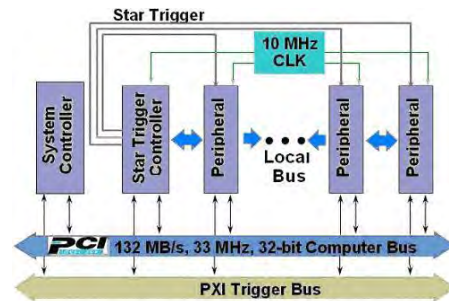
Delta sigma based acquisition devices require three signals for synchronization. They are the sync pulse, start trigger and a reference clock. The sync pulse resets the internal counters of the acquisition device and the ADCs. The start trigger starts the acquisition. The reference clock ensures that the internal time-bases of difference acquisition devices do not drift with respect to each other.

Trigger Lines in PXI



The hardware platform used in this presentation is PXI. The rest of the presentation will focus on how to synchronize multiple PXI chassis together, but it is important to note how the timing and triggering signals are routed within a signal PXI chassis. The PXI standard requires a trigger bus that shares triggers between slots. It also defines a system reference clock of 10MHz.

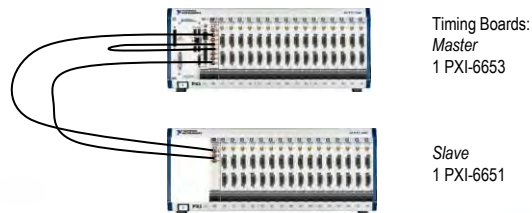
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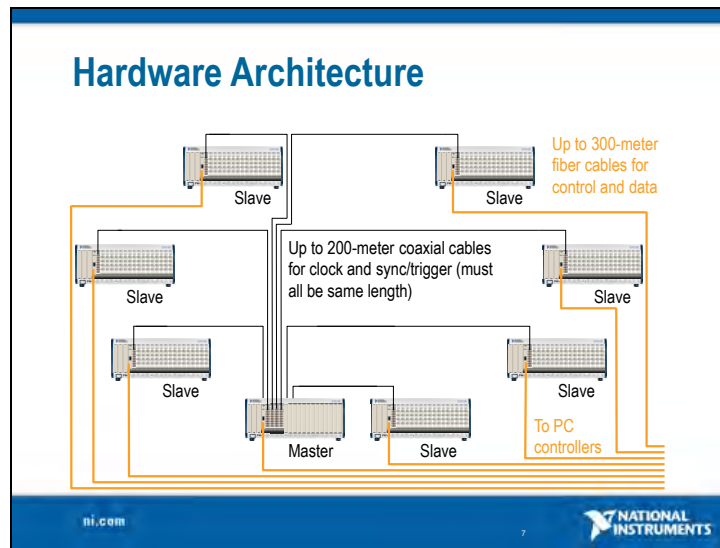
Signal based Synchronization

- Timing signals are physically routed to each chassis.



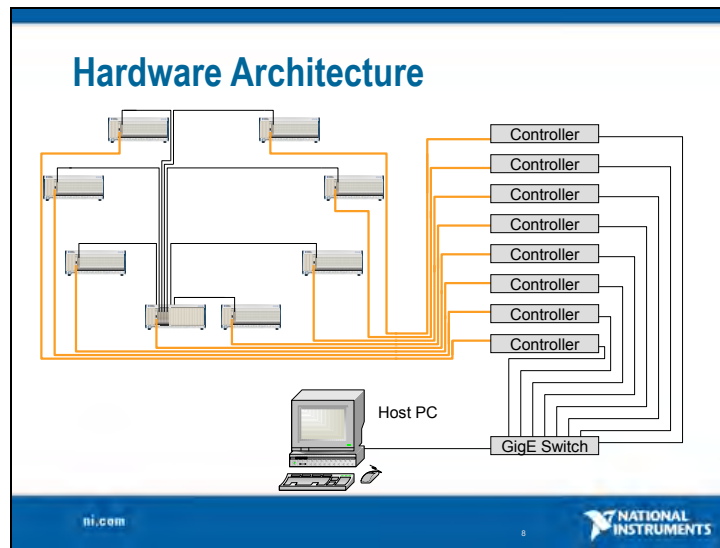
In a signal based synchronization scheme, the timing and triggering signals are routed directly from one chassis to another chassis over cables. In this scheme, there is always a single master timing chassis and multiple slave chassis. Since the signals are routed over cables, the level of synchronization can be very tight and very repeatable.

For DSA devices like the PXI-446X and PXI-449X, specialized timing and synchronization modules like the PXI-665X override the 10 MHz reference clocks on the instrumentation backplane.



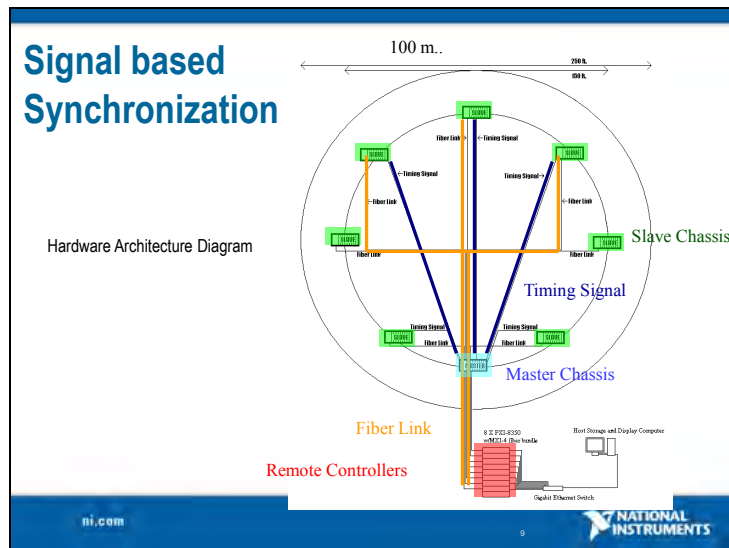
This application was built on a distributed system that is accessed by multiple remote clients. The Multi-client, single server architecture provides a flexible and expandable approach to the system since the goal is to increase the channel count. A master chassis controls timing and triggering. Slaves distribute clocks, control local acquisition, and store data to disk. A Central CPU can serve as master data storage (move data over ethernet) and analysis engine or as remote monitoring only. This required a fairly complicated data communication between various computers.

For DSA devices like the PXI-446X and PXI-449X, specialized timing and synchronization modules like the PXI-665X override the 10MHz reference clocks on the instrumentation backplane. Cables of matched lengths distribute the timing and triggering signals throughout the system, allowing up to 200 meters of instrumentation chassis separation while still maintaining tight synchronization between hundreds of channels at less than 0.3 degrees of phase mismatch at up to 93 kHz.



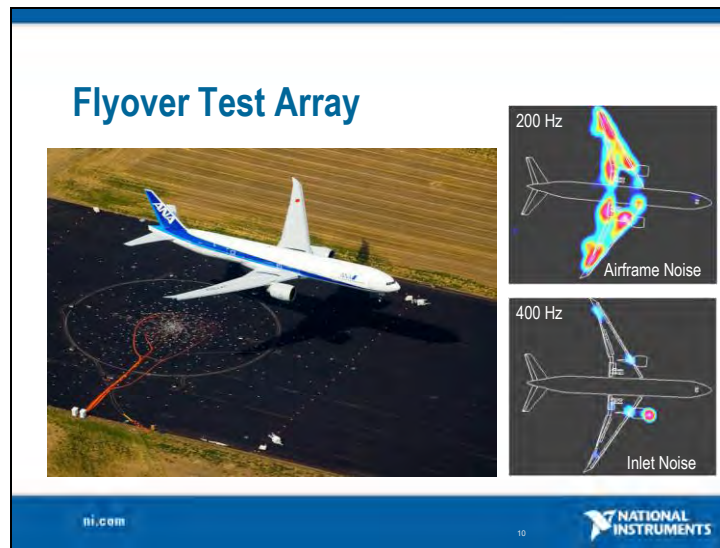
High channel dynamic signal acquisition applications have some important issues to consider including data throughput, streaming to disk, data processing, the user display and network activity. Depending on the requirements of the system, tradeoffs can be made to optimize one performance vector over another.

For scalable systems from 200 – 1000 or more channels a system architecture using multiple PC based controllers and multiple chassis was proposed for this application. In this architecture, a master chassis controls timing and triggering. The master chassis creates and distributes clocks, and the slave chassis propagate clocks on the backplane. Slaves distribute clocks to modules within, control local acquisition, and store data to disk. A central CPU serves as a master data storage (moving data over Ethernet) and analysis engine. This allows local acquisition, analysis and data storage with a single host used for remote monitoring via Ethernet and centralized timing and synchronization.



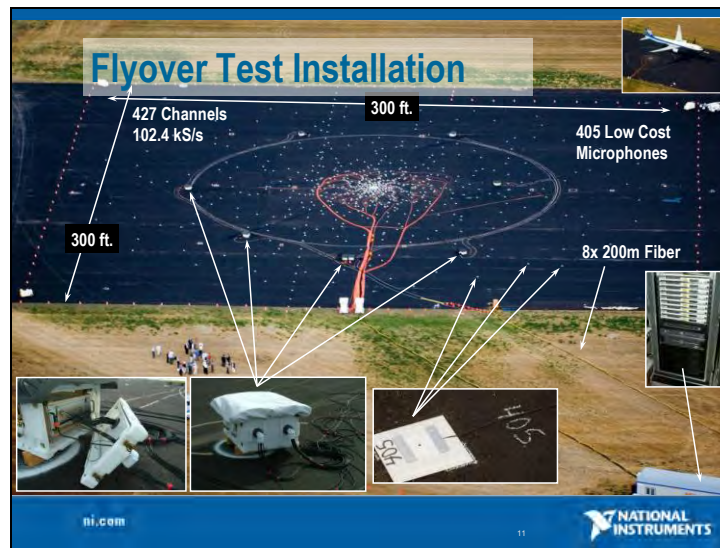
This schematic shows a more realistic and complicated implementation of a multi chassis synchronization architecture. Here, there is a master chassis which provides all of the timing signals for the entire system. Each of the slave chassis imports the timing signals are routes them to the acquisition devices. Since the timing signals are all routed by physical cables, each of the slaves chassis must be within 200m of the master timing chassis. This limitation of 200m is due to the drive strength of the timing devices.

In this system, there is a single PC for each PXI chassis. This is so that the system can handle the high total system bandwidth which is required. The PCs are connected to the PXI chassis over a MXI fiber optic connection. Once a set of data is finished being collected, the data is aggregated in a single host server for data analysis.



Here's a picture of a Boeing fly-by test where they used this signal based architecture when measuring the acoustic emissions of a 777. The small white dots are the microphones, the medium sized white dots are the PXI chassis. This is a 400 channel system that has been expanded to over 800 ch.

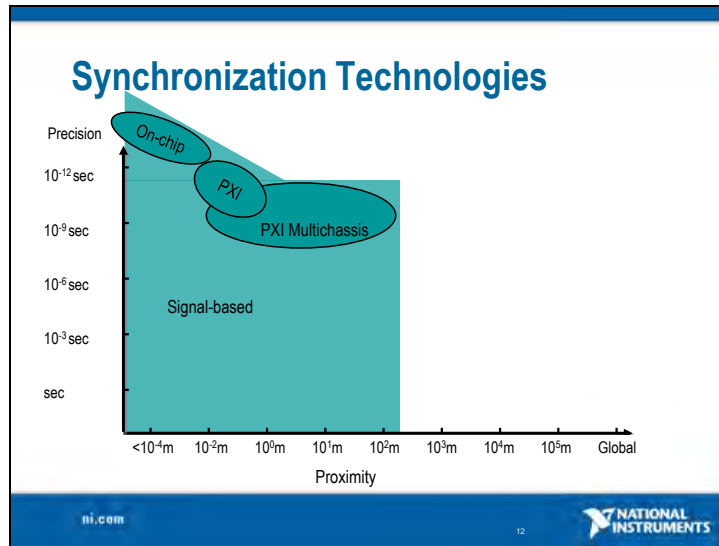
Signal based synchronization does provide a great way to have a high level of synchronization in a large, flexible system architecture. One limitation of a signal based system is the distance between the master timing chassis and a slave chassis. If you need to synchronize a system across an area more than 200m, a time based synchronization scheme is more appropriate.



Acoustic beam forming can be used in aircraft pass by noise tests to measure and distinguish engine and airframe noise sources in addition to testing quiet flight operation procedures. The use of phased arrays of microphones in the study of noise sources is being more widely used and should increase as the cost of instrumentation goes down. When properly used, arrays can be used to extract noise source distribution on full-scale and wind tunnel models.

With more channels, Boeing has been able to get higher resolution to distinguish noise sources. This information can be used to make design or operational changes. Their ultimate goal is to increase the channel count to over 1,000 channels. The flyover noise map with a phased array “acoustic camera” identifies opportunities for noise source reductions and distinguishes between engine and airframe sources.

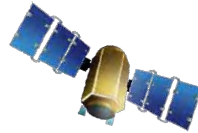
In the first stage of the project in 2001, Boeing deployed a system that could handle a microphone array up to 264 channels. They ran into channel bandwidth limitations in the total number of channels that their system architecture allowed. The system required a centralized data system architecture where all the chassis had to be co-located which required over 30 miles of cable. They also faced challenges in synchronizing multiple instrumentation chassis, the cost per channel, the dynamic range as well as the data turnaround (time to retrieve acquired data).



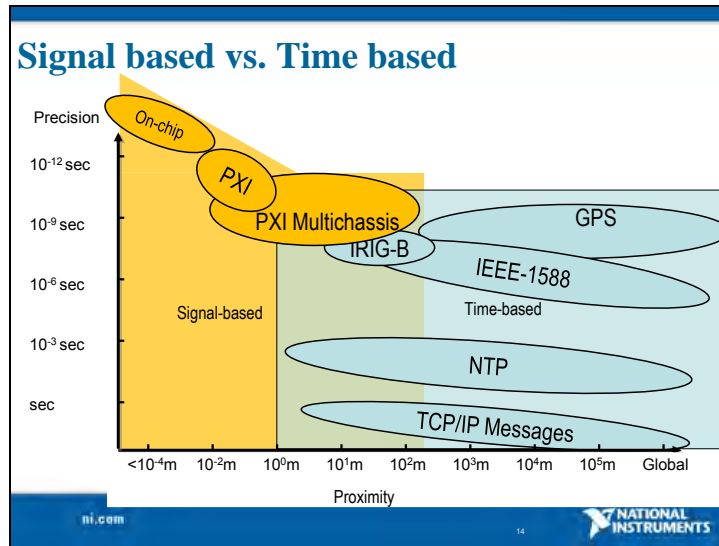
100 square meters appears to be a practical limit for the tightest synchronization vs. proximity to the instrumentation in a signal based architecture for dynamic signal acquisition. For arrays of IEPE/ICP[®] type sensors such as accelerometers and microphones, this can be extended with longer cable lengths from the instrumentation depending on the frequency of interest and constant current source provided.

Time based Synchronization

- Timing signals are based off of a common time reference. This could be GPS, IRIG-B, or IEEE-1588.



In a time based synchronization scheme, we still have to provide the same timing signals as in a signal based scheme, but the way in which we do so is different. All of the timing signals, triggers and clock, are based off of a common time reference. Examples of time references are GPS, IRIG-B, and IEEE-1588. For the rest of this presentation, we'll focus of the use of GPS as the most common time reference used in wireless architectures. Similar implementations could be done for the other time references.



Let's look at a comparison of signal based synchronization and time based. The X-axis shows proximity or distance while the Y-axis shows the amount of precision in the synchronization method. This is a generalized graph and is not specific to DSA applications.

Here we see signal based synchronization schemes. We can see that the precision of the synchronization is directly related to the distance of the synchronization.

These are some types of signal based synchronization schemes. In comparison to signal based, the same level of precision can't be achieved. Unlike signal based, the precision of time based synchronization schemes is not as correlated to the distance of the synchronization. Let's look at how we can use GPS to synchronize a large channel DSA system.

Timing Signals - DSA

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 - Resets internal counters and ADCs
- Start Trigger
 - Starts acquisition
- 10 MHz Reference Clock
 - Used as reference clock by internal sample clock

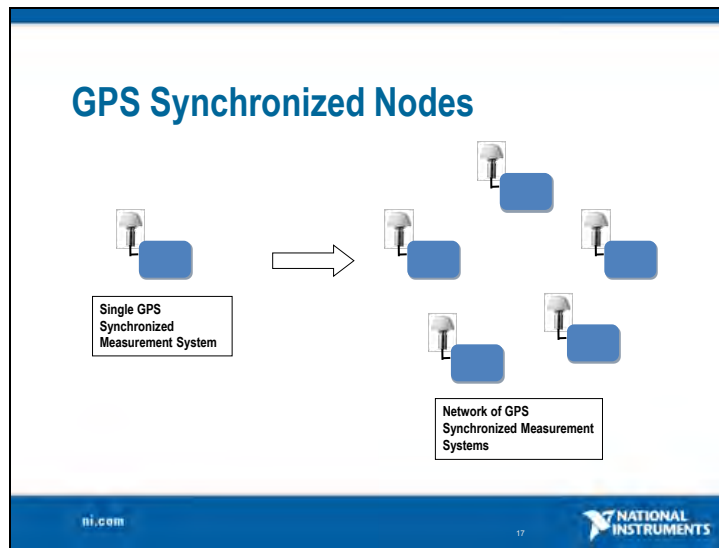
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GPS, IEEE 1588 and IRIG-B Timing and Synchronization for PXI

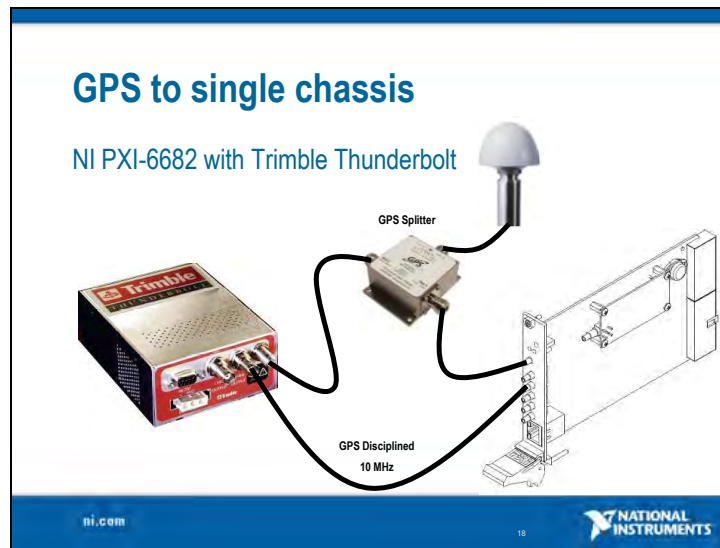
- GPS receiver
- Triggers
- Clocks



In order to synchronize a PXI chassis to GPS, we need a GPS receiver with triggering capabilities. The PXI-6682 is a GPS receiver and has the ability to generate triggers at specific GPS times. We can use this feature for both the Sync Pulse and Start Trigger. The Trimble Thunderbolt has the ability to generate a 10MHz clock which is locked to the GPS signal. This 10MHz clock can be used as the 10MHz reference clock for the PXI chassis.



Once a single PXI chassis is synchronized to GPS, it is easy to expand the system with other synchronized PXI chassis. In this system architecture, each node is considered a timing master since they do not rely on timing signals from any other system. These systems can be located anywhere that a GPS signal can be received combined with a wireless network, virtually removes any location or cabling constraints.

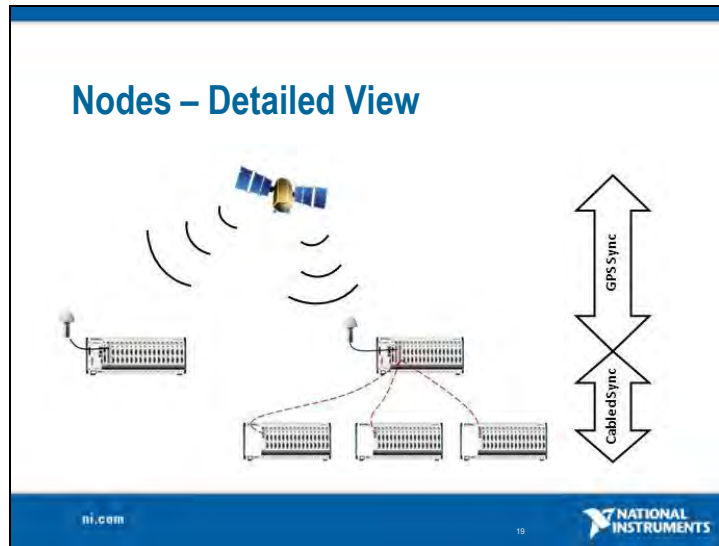


The Trimble Thunderbolt has the ability to generate a 10MHz clock which is locked to the GPS signal. This 10MHz clock can be used as the 10MHz reference clock for the PXI chassis. A GPS splitter is required to divide antenna signal for both the PXI-6682 and the Trimble Thunderbolt.

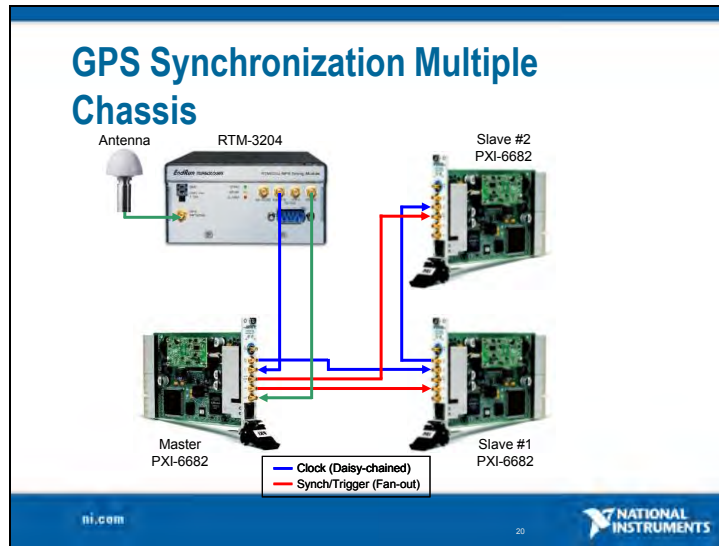
Just as with a signal based architecture, in order to synchronize DSA devices you need to provide the three timing signals. Two of the signals are triggers. These are the Sync Pulse which resets the device's internal counters and ADCs as well as the Start Trigger which begins an acquisition. The third signal is a 10MHz clock. The DSA device will phase lock loop (PLL) its internal clock to this 10MHz signal.

In this case a timing and synchronization module like the PXI-6682 which provides GPS time, location, and velocity; IRIG-B decoding; and an improved implementation of IEEE 1588 was used. This provides the capability for time-stamping and triggering measurements or events across large physical objects or distances. In addition, you can use the PXI-6682 to synchronize the start of distributed PXI systems at specified future times.

This module has the ability to generate triggers based on GPS time (these are called Future Time Events in the NI-Sync API). Future Time Events can be used for the Sync to stay synchronized to the GPS signal so it does not continuously drift as a non-disciplined clock does. For the best measurement synchronization needed for higher frequencies, the 10 MHz clock needs to be disciplined to GPS. A GPS disciplined clock is continuously adjusted to stay synchronized to the GPS signal so it does not continuously drift as a non-disciplined clock does.



If we take a closer look at each of those GPS synchronized nodes, we see that they can come in different flavors. A node could consist of a single PXI chassis or it could be multiple PXI chassis. In the case of multiple PXI chassis, the master timing chassis is connected to the GPS antenna and then synchronizes with the other chassis via a signal based scheme (cables). This is useful if your sensors are not equally spaced throughout the test area. If you have a high sensor density section, you can add more acquisition devices without needing to add more GPS antennas. There's no reason to have multiple GPS antennas right next to each other.



The RTM3204 GPS timing module is a very high-performance unit designed specifically for stringent holdover requirements and portable applications. With the high-stability Rubidium option it can maintain a timing accuracy of < 1 microsecond over 24 hours following loss of GPS signals. Designed for 24V battery-powered systems, it accepts a wide range 18V to 30V power input and requires only 80 cubic inches of mounting space.

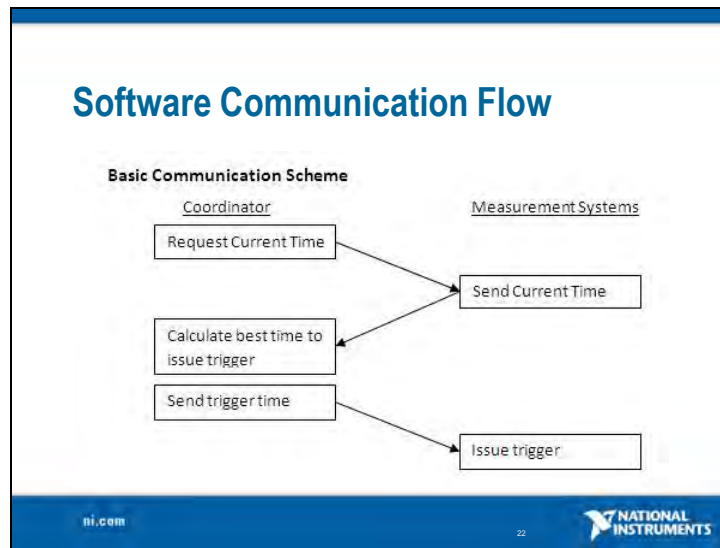
Software Architectures

- Long term continuous monitoring
- Fixed Install

vs

- Operates as single system
- Tests run at defined times

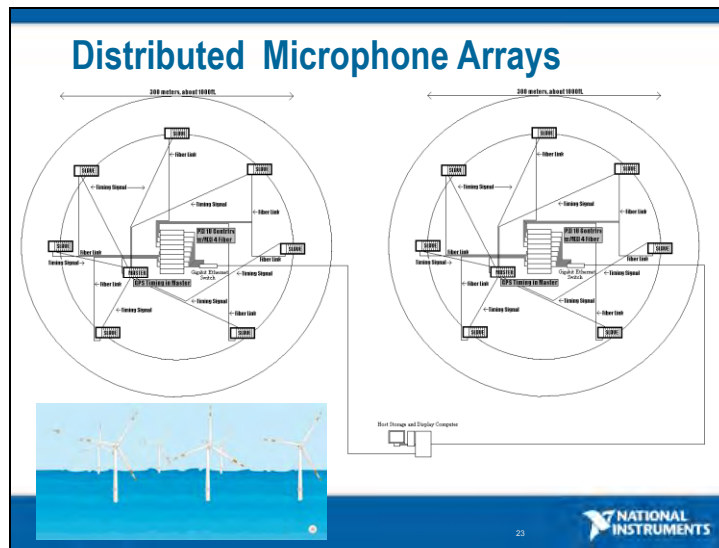
GPS can be used in a variety of software architectures.



There are several ways that a large GPS system could be controlled in software and the type of application is the determining factor in which one should be chosen. There are two basic paradigms for the software synchronization.

One is that each subsystem operates more or less independently. In this case, the system is truly a collection of subsystems whose data is time-stamped and can be correlated through post processing. This is more common for a fixed install or long term continuous monitoring system where individual subsystems can come on and off line whenever needed.

The other paradigm is when the system is used as a single large acquisition system. The output of the system is generally multiple logs for individual tests and it is typically controlled through a user interface. A “time coordinator” is used to send commands and coordinate all of the subsystem’s actions in time. Here is an example of the type of coordination which is taking place. When issuing a trigger, the coordinator requests the current time from all of the subsystems, calculates the best time to issue the trigger, and sends the command to issue the trigger at a certain time.



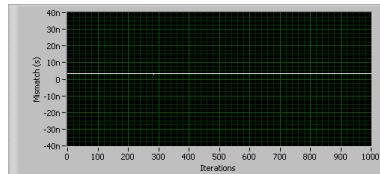
This is a conceptual system design of synchronizing multiple microphone arrays. It has been deployed in measuring the exposure of marine animals to noise, especially marine mammals, in the vicinity of offshore wind farms like the Alpha Ventus wind farm.

The goal of this research project is the measurement of the operational underwater sound emission of different types of 5 MW offshore wind energy converters (OWEC) at the offshore wind farm Alpha Ventus under varying boundary conditions. See www.rave-schall.fh-flensburg.de for more information about this project, www.rave-offshore.de for more background information about the "Research at Alpha Ventus" project, and www.alpha-ventus.de for more information about the windfarm.

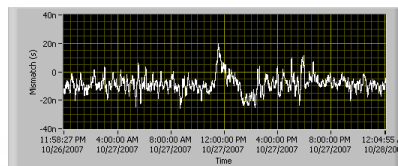
The noise production of OWEC and the underwater sound propagation are influenced by many parameters (boundary conditions), such as wind velocity, wind direction, sea state, water height, water flow profiles, water temperature, water temperature profiles, salinity, etc. To this end a total of 5 hydrophones will be positioned about 3 meters above the sea bed near 2 OWEC and near the research platform FINO1, which is located at a distance of 400 m from the wind farm. In addition acceleration sensors will be mounted at the underwater and over-water sections of the OWEC towers. GPS is used for synchronizing the 3 different dynamic data acquisition systems. The PXI systems consists of a small PXI chassis and controller, two PXI-4462 modules (only one 4462-board in the FINO1 system) and a PXI-6682

Synchronization results

Signal based



Time based (GPS)



We can see that the signal based approach provides the tightest synchronization in the above chart and that it is extremely repeatable at less than 10ns of mismatch between PXI chassis. For GPS synchronization, the synchronization results vary over time, but are bounded by certain limits. This is due to the fact that everything is locked to a single time reference (GPS) so they don't drift apart. This graph shows 2 days worth of testing.


Phase Array Requirements

- +/- 25 ns of mismatch between two independent PXI chassis (less than +/-1° at 92kHz)

		Phase Mismatch		
		+/- 0.5°	+/- 1°	+/- 2°
Bandwidth	10 kHz	+/- 138 ns	+/- 276 ns	+/- 552 ns
	20 kHz	+/- 69 ns	+/- 138 ns	+/- 276 ns
	92 kHz	+/- 15 ns	+/- 30 ns	+/- 60 ns

With GPS synchronization, multiple PXI chassis can be synchronized together with an accuracy of +/-25ns. If we convert this to phase, this is equivalent to +/-1 deg at a 92kHz bandwidth. Even though GPS synchronization is not as tight as signal based synchronization, it is still very tight and good enough for all but the most stringent DSA applications.

Donghai Bridge - Structural Health Monitoring with PXI



[Structural Health Monitoring of the Donghai Bridge with NI LabVIEW and PXI](#)

Bridge Requirements

- 20-mile long, operating in harsh conditions
- Long-term vibration monitoring with low-maintenance
- High-level software to manage, analyze, and report on entire scale

Solution

- 14 PXI systems synchronized over GPS
- Continuous 24x7 operation for over 2-years

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Another application where GPS is critical is the structural health monitoring system of the Donghai Bridge in the East China Sea. This bridge is over 20 miles long and the engineers were tasked with creating a long-term vibration monitoring system. Once again, it's not feasible to share timing signals across these types of distances. The system was implemented using 14 PXI systems synchronized to GPS.



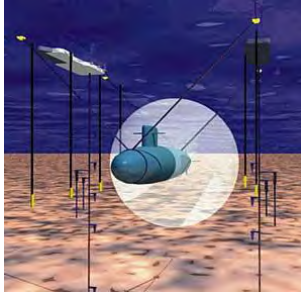
As China's first sea-crossing bridge, the Donghai Bridge, a cable-stay bridge stretching across the East China Sea has a full length of 32.5km portion above water. The main navigation span, which is of 420m, has navigation capacity of 5000t, navigation height of 40m. Obviously, the monitoring system for the Donghai Bridge is large-scale with a variety of quantities to be monitored and transmitted.

When the RSSI algorithm is applied to Donghai Bridge to do on-line monitoring, the acceleration signals from tens of accelerometers mainly residing around the main navigation span are used to identify the corresponding resonance frequencies. The well synchronized acceleration data from these accelerometers are time-stamped and then transmitted over network to the monitoring workstation. There are 14 workstations distributed over the bridge for simultaneous acquisition and control, which is guaranteed by a GPS signal.



The measurement systems for the Donghai Bridge are spread through the bridge body. The bridge is divided into several segments, each of which includes a data acquisition station connected to a GPS receiver. The distances between these stations are several to tens of kilometers. The overall data acquisition system is composed of these data acquisition stations distributed at selected spots along the 32 km. long bridge

GPS Synchronization of Independent Systems



The Acoustic Research Detachment (ARD) of the Naval Surface Warfare Center's Carderock Division (NSWCCD) is in Bayview, ID on Lake Pend Oreille. The lake's depth (1,150 ft) provides an excellent environment for underwater acoustic signature research testing.

Navy's Acoustic Research Detachment

- Scaled submarine (mobile and stationary) and surface ship models used for R&D evaluations of
 - Machinery Systems
 - Piping Systems
 - Propulsion Systems, etc.
- Underwater radiated noise coupling from:
 - Structureborne Noise
 - Airborne Noise
 - Fluidborne Noise
 - Hull Flow Noise



Units under test include -

Scaled submarine (mobile and stationary) and surface ship models used for R&D evaluations of

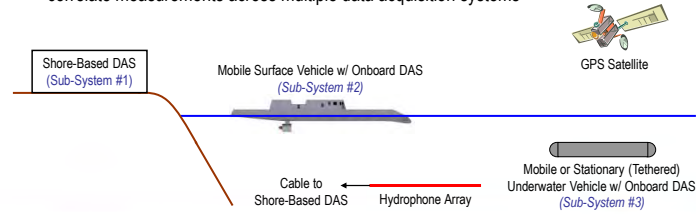
Machinery Systems
Piping Systems
Propulsion Systems, etc.

Underwater radiated noise coupling from:

Structure-borne Noise
Airborne Noise
Fluid-borne Noise
Hull Flow Noise

GPS Synchronization Between Independent Systems

- Several data acquisition systems used simultaneously for:
 - Onboard vehicle sensors
 - Multiple overboard hydrophone arrays
- Each system operates independently
- Precise synchronization required for most tests
- **GPS synchronization** of each sub-system allows the analyst to correlate measurements across multiple data acquisition systems



With several data acquisition systems used simultaneously for onboard vehicle sensors and multiple overboard hydrophone arrays, GPS synchronization allows the analysts to correlate measurements across multiple data acquisition systems.

GPS Synchronization Requirements

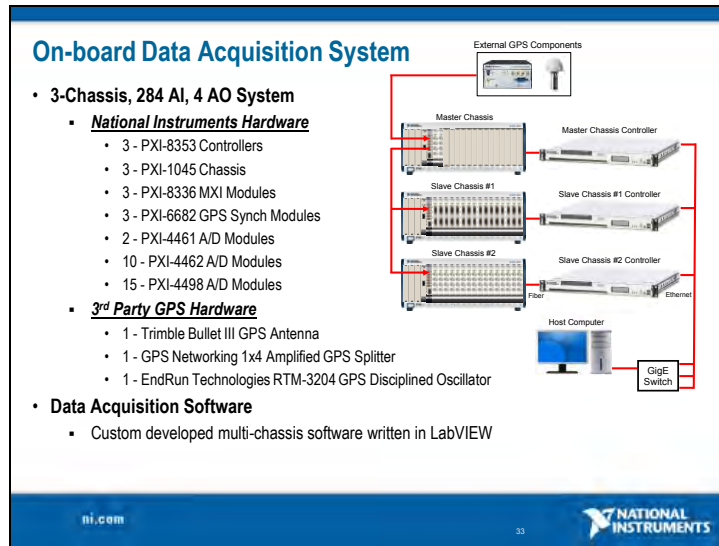
- **Synchronization Accuracy:** $\pm 1 \mu\text{s}$
- **Synchronization Holdover:** > 24 hours
- **Trigger Time Stamp:** GPS Time-of-Day to the whole second
- Holdover ensures precise synchronization even if GPS signal is not present and is achieved via a GPS disciplined oscillator
 - Desired for:
 - Surface vehicle testing
 - Tethered submerged vehicle testing
 - Required for:
 - Untethered submerged vehicle testing
- Requirements imposed on each data acquisition sub-system
 - GPS antenna has line-of-sight to satellites but could experience periodic drop-outs
 - No GPS signal available underwater when not tethered

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Every channel in the multi-chassis PXI system must satisfy the following requirements to sufficiently correlate measurements with other ARD data acquisition systems operating simultaneously and independently:

- Synchronization Accuracy: ± 1 ms
- Synchronization Holdover : > 24 hours
- Trigger Time Stamp: GPS Time-of-Day to the whole second
- Holdover ensures precise synchronization even if GPS signal is not present and is achieved via a GPS disciplined oscillator
 - Desired for:
 - Surface vehicle testing
 - Tethered submerged vehicle testing
 - Required for:
 - Untethered submerged vehicle testing

Requirements imposed on each data acquisition sub-system



This is an overview of the hardware used for the first on-board data acquisition system of a mobile surface vehicle capable of handling up to 284 ch. 24-bit analog input and 4 channels of 24 bit AO.

GPS Synchronization Approach – Key Elements

GPS Satellite & Antenna

- Provides GPS time and 1 PPS signals

EndRun RTM-3204

- Generates a disciplined 10 MHz signal using internal Rubidium oscillator from GPS 1 PPS
- Generates an IRIG-B DC-level time code from GPS time



National Instruments PXI-6682 (Master Chassis)

- Receives and distributes disciplined 10 MHz signal to master chassis backplane and slave timing modules
- IRIG-B time code used for triggering and time stamping



Key elements of a GPS synchronization approach include GPS satellites with antenna, a GPS timing module, and a system timing and triggering module for the instrumentation.

GPS Synchronization Approach – Common Scenarios

Tethered Static Underwater Vehicles (No Disciplined Oscillator)

- GPS received on shore & converted to fiber optic → Delivered to vehicle & converted to copper
- PXI-6682 receives GPS 1 PPS, generates 10 MHz signal, and uses GPS time for time stamp
- GPS signal dropouts will compromise synchronization

Tethered Static Underwater Vehicles


- GPS received on shore → Disciplined 10 MHz signal generated → 10 MHz and IRIG-B signals converted to fiber optic → Delivered to vehicle & converted to copper
- PXI-6682 receives 10 MHz signal and uses IRIG-B time code for trigger time stamp

Untethered Mobile Underwater Vehicles

- GPS received onboard while on surface → Disciplined 10 MHz and IRIG-B signals generated → GPS antenna disconnected & vehicle submerged
- PXI-6682 receives 10 MHz signal and uses IRIG-B time code for trigger time stamp

Untethered Mobile Surface Vehicles

- GPS received onboard → Disciplined 10 MHz and IRIG-B signals generated
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Quiet Supersonic Jet Sonic Boom Tests Over Land



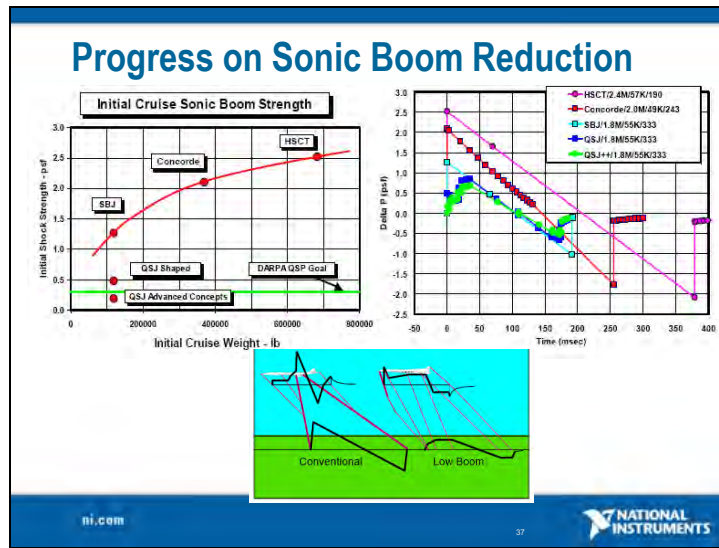
Progress towards a viable
Supersonic business jet
Requires elimination of prohibition
of supersonic over land flight

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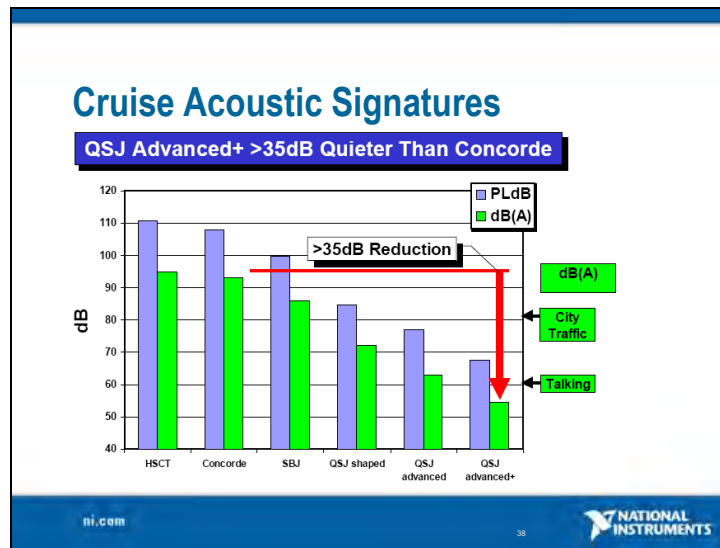
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Quiet supersonic flight over land appears increasingly viable, both technologically and economically, based on significant advancements in aircraft shape optimization. Commercial supersonic flight over land can only begin after modification of restrictions that are currently in place. Such modifications will require substantial justification that boom signatures generated on the ground by low boom aircraft like the QSJ (Quiet Supersonic Jet) are not objectionable to citizens. One of the next critical breakthroughs involves community scale surveys, measuring the public response to events that sound as benign as distant thunder. A scalable grid of National Instruments CompactRIO instrumentation has been developed and deployed in a risk reduction test, demonstrating unattended community scale measurements of sonic booms.

An advanced wireless architecture of a distributed, synchronized data acquisition system for the extended measurement of sonic booms that can be deployed in a variety of populated areas is overviewed. Designed to be distributed, scalable, low-cost and non-proprietary, it is capable of high quality field measurements suitable for certification agency discussions. The system consists of nodes that can be spread over a large area with 1 – 12 microphones similar to airport noise monitoring stations. These nodes will be controlled by a base station relative to data acquisition gains, filtering and start/stop recording commands via a secure peer to peer wireless access.

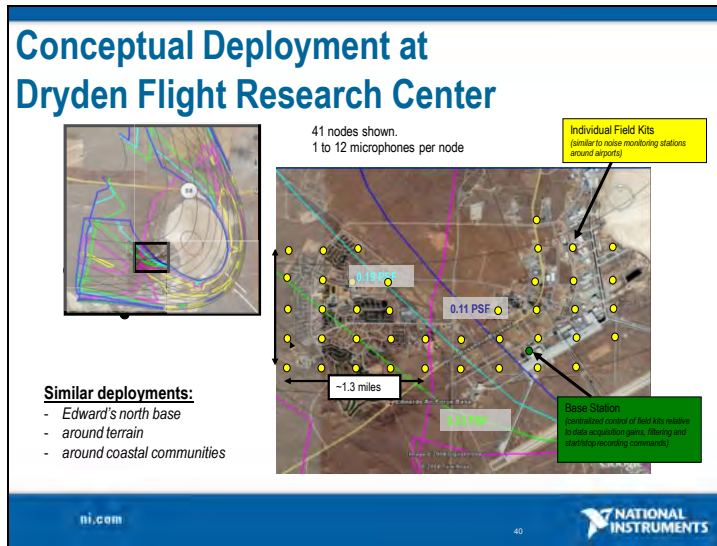


Impulsive noise is caused by initial and final abrupt pressure rises. Substantial progress is being made to reduce sonic boom strength.



The relationship between the perceived level, PLdB, of sound (loudness or noisiness) is shown to be a function of the sound pressure squared and the sound frequency squared. A logarithmic formula employing this basic relationship between perceived level and pressure and frequency has been developed and is found to be as accurate as the more complex methods currently in use. The results are found to be more accurate than the complex methods currently in use for the useful range of sound pressure levels and frequencies found to be associated with operational aircraft including helicopters, turbofan, turboprop and turbojet powered aircraft.

The perceived level of an aircraft takeoff or landing is demonstrated to be equal to the logarithmic sum of the peak perceived levels calculated for each one-third octave band. Effective perceived level (EPLdB) may be calculated by using the procedures contained in the Federal Air Regulations (FAR), Part 36, to correct for the duration of the sound 10 dB below peak level. PLdB and EPLdB show the highest relationship between subject ratings and the physical characteristics of the flyover sounds accounted for by any calculation procedure. The average rate of growth of annoyance (loudness or noisiness) for a diverse mix of aircraft operations ranging from low to high power levels is shown to be a function of $\log(k pf)_{12}$ for the low frequencies which propagate over long distances with relatively small power loss.



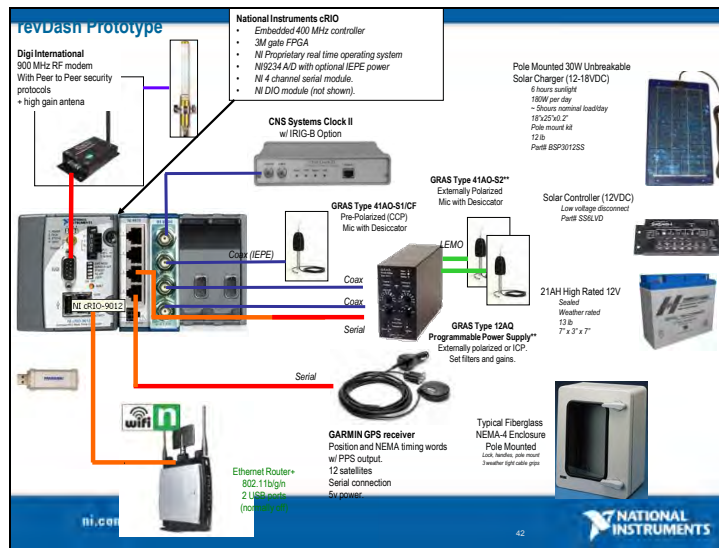
This is a conceptual deployment at the Dryden Flight Research Center where NASA has already conducted tests on buildings to measure and evaluate the effects of low amplitude sonic booms on commonly populated environments. The tests conducted during the experiments included indoor and outdoor human subjective response studies, as well as building structural and acoustic response measurements.

In this system, a base station provides centralized control of field unit wirelessly. Up to 41 nodes or individual field kits similar to airport noise monitoring systems are planned.

Timing Signals – Compact RIO

- Sync Pulse
 - Resets internal counters and ADCs
- Start Trigger
 - Starts acquisition
- Sample Clock Timebase
 - Clock that drives the Delta-Sigma ADCs

The system deployed here uses a slightly different instrumentation architecture called cRIO. Since both the cRIO and PXI DSA modules are based on delta-sigma converters, they both use very similar timing signals. One difference is that the PXI modules use a reference clock to lock to while the cRIO modules share their sample clock time-bases (oversample clocks) directly from one module to another.



This is a diagram of the components planned for the field measurement system. The heart of the system is a cRIO system. This is a rugged, reconfigurable deployment platform for embedded and control applications with low power requirements. Individual modules provide dynamic signal acquisition for 4 – 12 microphones. The system is battery operated with a solar panel in a NEMA enclosure that can be pole mounted to operate for long periods of time. An RF modem provides peer to peer security protocols along with a wireless Ethernet router. A serial port provides control over the signal injection to the microphones for calibration as well as input from the GPS receiver.

System Technical Requirements


- **Signals:**
 - Outdoor sonic boom signatures (dynamic pressure)
 - Time code for synchronization. GPS coordinates.
- **Sensors / Recording:**
 - Local Channel Count: 4 to 12 channels of A/D depending on the application.
 - Frequency range: 1 Hz to 20 kHz (ICP mics). DC to 20 KHz (externally polarized mics).
 - Maximum pressure: carpet msmts: < 1 psf (125 dB re 20 μ Pa)
focus msmts: < 10 psf (145 dB re 20 μ Pa)
 - Dynamic Range: >104 dB / 24 bit
 - Mic Noise Floor: <20 dBA (NI9234 dynamic range limitations may cause higher actual noise floor).
- **Instrument Control (not simultaneous with data logging)**
 - 900MHz RF Modem including sleep/wake scheduling.
 - GRAS Programmable Microphone Power Supplies. Settings include external polarization voltage or IEPE power, gain, filtering and signal injection calibrations. Sleep/wake scheduling.
 - Ethernet interface to wireless radio (802.11n(DRAFT)). Obvious comms plus sleep/wake scheduling.
 - GARMIN GPS receiver interface to pulse-per-second edge and and NMEA timing words
- **Unattended – Portable – Scalable**
High Quality performance specifications that are amenable to incorporation into future VOLPE / DOT regulatory standards.


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Base Station Software Requirements

1. *Manage remote targets on WWAN*
2. *Get hardware status*
3. *Set hardware status*
 - *Optional reset of all logs. Clear disk space.*
 - *Set sleep/wake schedules for modem, radio, power supply*
 - *Set NI9234 filters. AC/DC coupling. IEPE*
4. *Command data logging*
 - *Trigger logging for fixed UTC times.*
5. *Perform Local QC of Individual Time Series*
 - *Command cRIO to compress individual time series and transmit.*
 - *Also transmit scale factor, gains, etc.*
 - *Base performs audio playback, computes spectra and metrics.*
 - *Plots waveforms and spectra.*
6. *Command Remote QC of Individual Time Series*
 - *Send processing command.*
 - *Receive event logs with metrics, SNR, etc.*
 - *Animate metrics vs time of arrival on boom carpet.*
7. *Command Signal Injection Calibration*



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The base station has to manage the remote field units on the wireless wide area network, acquire and set the hardware, command data acquisition and logging.

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Field Node Target Software

1. Instrument Control
 - Manage sleep/wake schedule for modem, radio, and power supply.
 - Set power supply features (IEPE, Polarization voltage, Gain, Filters).
 - Monitor GPS receiver pulse-per-second and NMEA timing words.
 - Get cRIO status. Manage disk space, etc.
2. Microphone Calibrations
 - Perform signal injection cal as commanded by the base station.
 - Perform local field calibrations using pistonphone. Wireless interface?
 - Calculate actual sensitivities. Log. Transmit results to base on command.
3. Data Logging
 - Save raw microphone time series based on start/stop triggers.
 - Log voltages (or pressures) as signed integers?
 - Saving to USB flash memory on controller front panel.
 - Absolute time stamp with goal 1 mSec accuracy for at least the first sample.
 - Upon completion of data logging send base station an event log indicating start time, end time, file size and peak overpressure/time of arrival plus other signature metrics. Processing by controller. Transfer initiated by base station.
4. Support Base Station QC of Individual Time Series
 - On command compress an individual time series and transmit.
 - Also transmit scale factor, gains, etc.

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The field data acquisition units have to manage instrument control, microphone calibration, data logging and prepare data for uploading to the base station.

1. Instrument Control
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Conclusion

- GPS Time-based Synchronization (Wireless) offers high level of synchronization for Sound and Vibration Applications
- Growing number of Advanced Wireless Applications

It can be very useful to correlate data acquired from different systems particularly dynamic signals from accelerometers or microphones simultaneously while maintaining the phase and amplitude relationships with precise timing. Synchronizing input from a large microphone array is a matter of routing the right clocks and triggers across the proper pathways.

High channel count as well as large size of the units under test, provides challenges in synchronization to maintain these phase relationships. Signal based time refers to unit-less ticks or events that mark an instance in time. These are often electrical signals, such as a voltage transition. It is a well developed technology and depends on auto routing of which clocks and triggers to use to auto synchronize multiple identical devices.

Time based synchronization is in its infancy. Time based synchronization refers to the use of time with units to coordinate and control different systems. Time based synchronization via GPS, IEEE-1588 or IRIG-B requires no direct connection and achieve good results over much longer distances.