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Instrumentation Synchonization Techniques for Large Microphone Arrays

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In many acoustic measurement applications such as large microphone arrays, there is a need to correlate data acquired from different systems or synchronize systems together with precise timing. Signal Based and Time Based are the two basic methods of synchronizing instrumentation. In Signal Based synchronization, clocks and triggers are physically connected and routed between systems. This provides the highest precision synchronization and is well developed. For some applications, size and distance constrains physically connecting the systems needed for making measurements though the inter-channel phase information of simultaneously sampled signals is crucial. In Time Based synchronization, system components have a common reference of what time it is. Events, triggers and clocks can be generated based on this time. This is an overview of how a variety of time references including GPS, IEEE-1588, and IRIG-B can be used to correlate and synchronize measurements anywhere in the world with precision with and without a direct connection between the measurement systems. The level of precision of the variety of methods that can be used for time-stamping, generating a trigger at a user specified time as well as synchronizing multiple instrumentation types is covered.

1 Introduction

It can be very useful to correlate data acquired from different systems particularly dynamic signals from microphones or hydrophones 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.

2 Signal Based Architecture

In order to synchronize dynamic signal acquisition devices (DSA) in a PC based architecture such as PXI (PCI eXtensions for Instruments) you typically need to be able to provide three timing signals. Two of the signals are triggers. These are the Sync Pulse which resets the device's internal counters and analog to digital convertors (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. (Figure 1)

To create a system scalable to thousands of channels which might be required in a large microphone array, multiple PC based controllers and chassis are needed. In this architecture, a master chassis controls timing and triggering while slave chassis distribute clocks, control local acquisition and store data to disk. In this architecture, a master chassis controls timing and triggering while slave chassis distribute clocks, control local acquisition and store data to disk.

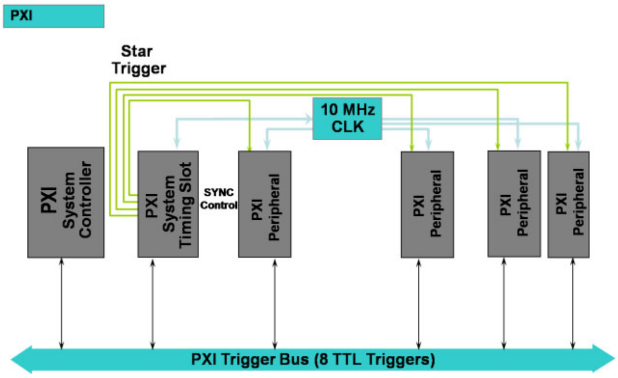

Figure1. PXI Synchronization Signals

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.

Below are results which show the typical amount of phase mismatch in time with a signal based architecture using two DSA devices in separate chassis. The phase difference between the signals was calculated and plotted on a graph. This process was repeated many times.The synchronization is extremely consistent as we would expect from a cabled synchronization method.

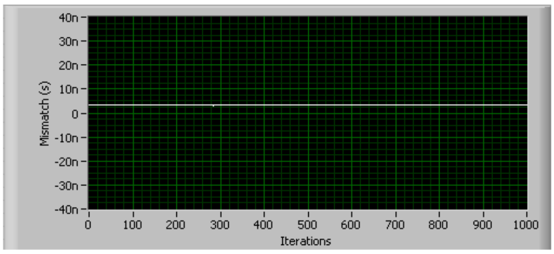

Figure 2. Mismatch results using cabled synchronization between two PXI chassis with PXI-4462 devices.

Figure 3 illustrates how this signal based timing architecture was used to synchronize 3 instrumentation chassis in a 288 ch. system for measuring the vibro-acoustic response of buildings exposed to sonic booms. In this application, a single computer was used for sampling rates up to 51.2 kS/s per channel [1]

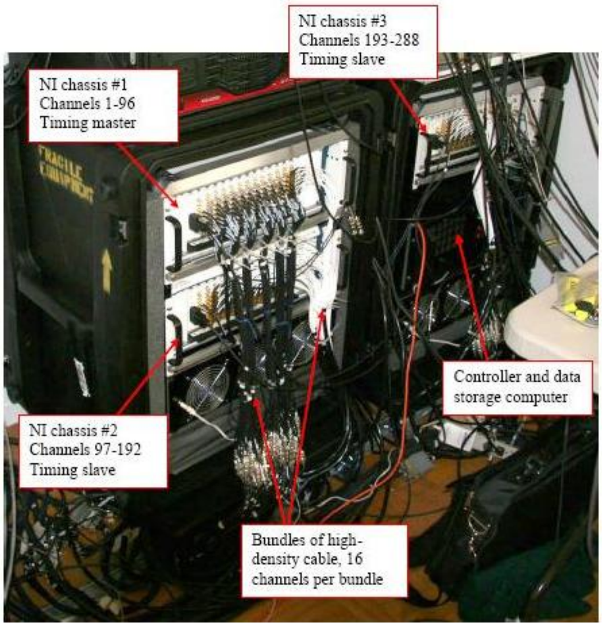

Figure 3. 288 ch. multi-chassis instrumentation system.

For larger arrays, cables of matched lengths can route 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.

This is what Boeing was able to achieve in their 427 channel microphone array distributed over 100 square meters used in 2005 for noise source location on flyover tests. This was used on the QTD 2 (Quiet Type Design 2) aircraft to validate noise reduction features. (Figure 4). The channel count is being increased to improve the resolution but there constraints in just how large the array can be due to cable length limits of a signal based architecture.

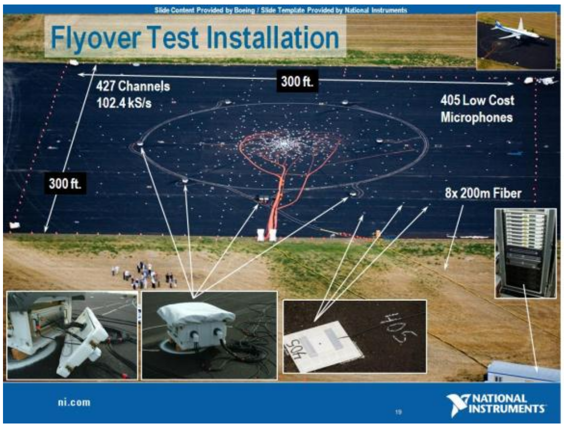

Figure 4. Boeing 427 channel microphone array

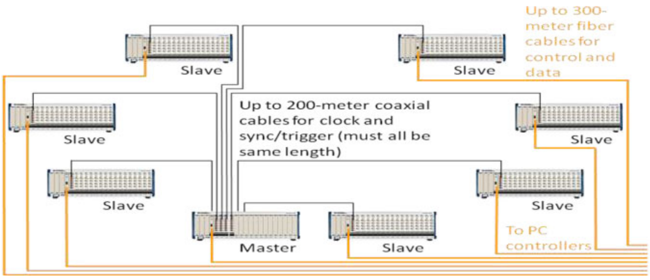

Figure 5. Architectural diagram of instrumentation for the microphone array.

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. (Figures 5 & 6) For arrays of IEPE/ICP® type sensors such as microphones, this can be extended with longer cable lengths from the instrumentation depending on the frequency of interest and constant current source provided.

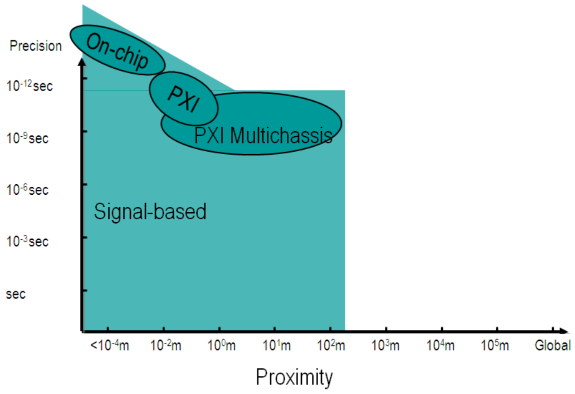

Figure 6. Signal Based precision vs. proximity.

3 Time Based Synchronization

Time based synchronization via GPS, IEEE-1588 or IRIG-B enables measurement systems to make measurements over the largest areas with precision theoretically matching signal based architectures. (Figure 7) All message based time transfer technologies work fundamentally the same way. One entity periodically communicates the current time while another adjusts the clock accordingly without the need of running timing cables to each measurement system. In addition, the data is always time stamped to a global time standard which allows the association of data with data sets from other systems.

For outdoor microphone arrays with systems separated by over 100 m., GPS technology has been available for some time and is relatively easy to implement wirelessly with an antenna. IEEE-1588 is a promising instrumentation technology and the techniques described here will be comparable to GPS. The initial standard was published in 2002 and only supports point-to-point connections. IEEE-1588-2008 includes synchronization on switched networks.

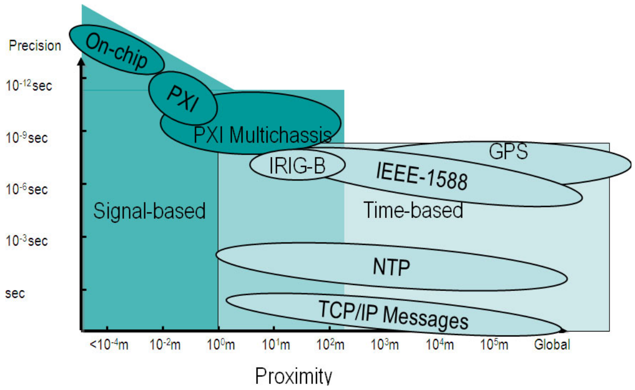

Figure 7. Time-based precision vs. Proximity

The question is what degree of precision is possible when using GPS in separated systems. Early tests with dynamic signal acquisition instrumentation on long cable stayed bridges, showed this technique worked well for modal analysis. The frequencies are much lower compared to acoustic analysis which can be up to 92 kHz when using scale models. [2]

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. (Figure 8)

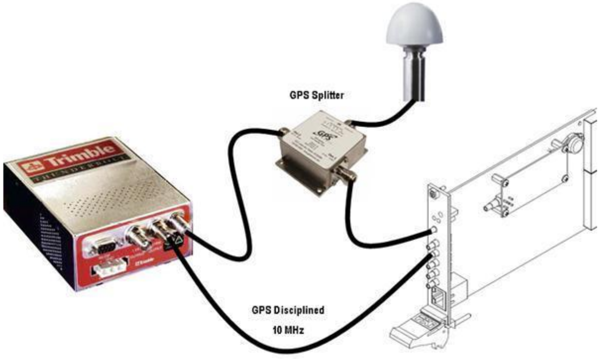

Figure 8. Hardware connections for GPS Disciplined clock.

Since no cabling between PXI chassis is required for synchronization, in order to expand a measurement system you only need to duplicate a GPS synchronized node. Figure 9 shows how a system can be expanded. GPS allows lots of flexibility in the overall system architecture. Each of the nodes does not need to be identical. For example, in many applications the sensors are not equally distributed over the test area. This means that the measurement devices also need to have a similar physical distribution. With GPS synchronization, one node may contain only 16 channels while another has 400 channels. Figure 9 shows how to synchronize a single PXI chassis up to many PXI chassis to a single GPS antenna.

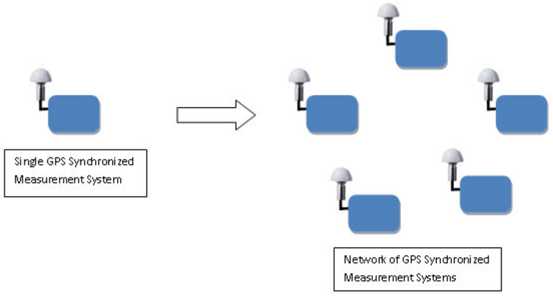

Figure 9. Expansion of a single GPS synchronized measurement system. Each node may contain a different number of measurement channels.

When multiple systems are synchronized together, a coordinator is required to get all of the systems working together. The coordinator is responsible for querying all of the systems for their current times, calculating the best time to send a future time event and relaying the results back to each system. The coordinator software can reside on any PC which can communicate with all of the measurement systems over TCP/IP. (Figure 10) It could even reside on one of the measurement systems.

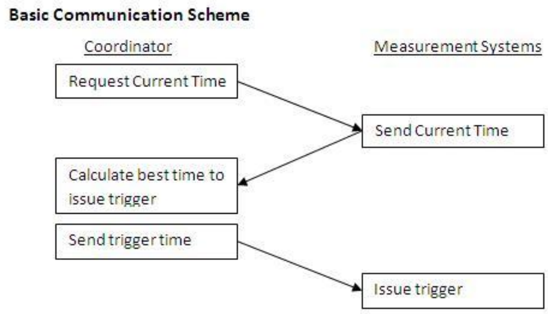

Figure 10. Basic communication flow between coordinator and measurement systems.

Once the data is acquired, the most common processes are to:

- Save the data to the local hard drive for post processing.
- Stream the data to a central server over TCP/IP for live monitoring.
- Perform analysis on the data as it is being acquired and return results to central server.

Typically, not just one of these is performed in an application, rather a combination of them. The GPS examples linked below will save all of the data to the local hard drive as well as stream a single channel over TCP/IP to the “Coordinator”. This allows for some basic monitoring of the data as it is being acquired. Once the acquisition is complete, the data files from each measurement system can be combined in a single location for processing or data storage

4 Results

The tightness of synchronization is an important factor to consider when determining which kind of synchronization scheme is required. With a cabled synchronization solution, you can achieve the tightest accuracy possible, but your system is constrained by the length of the cables possible. With a GPS synchronization scheme, the timing accuracy is reduced due to the error in the GPS signals, but there are no restrictions on the lengths of the timing cables since there aren’t any.

Below are results which show the typical amount of phase mismatch in time between each of these synchronization schemes (Figure 11). In each case, the same signal from a function generator (1 kHz sine wave) was provided to two DSA devices, each in a different PXI chassis. The phase difference between the signals was calculated and plotted on a graph. This process was repeated many times.

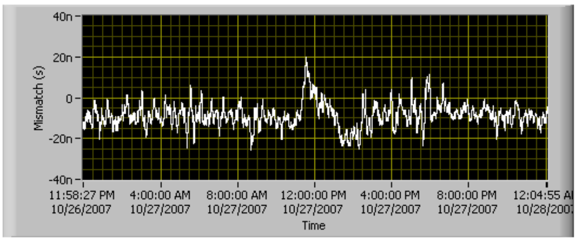

Figure 11. Mismatch results using GPS synchronization techniques between two PXI chassis with PXI-4462 devices. These results represent 24 hours of continuous testing.

5 Conclusion

From these results, it is evident that the cabled synchronization method provides very tight synchronization which does not vary from acquisition to acquisition. On the other hand, the GPS synchronization results do have variation in it. This variation is due to the difference between the GPS disciplined 10MHz clock and it is clear how the clock is continually corrected over time.

The results (Table 1) are presented as mismatch in terms of time. Typically, phase mismatch requirements are given in degrees. Here’s a chart which shows some common phase mismatch requirements in degrees and how they correspond to a mismatch in time.

	±0.5°	**±1°**	**±5°**
10 kHz	±139 ns	±278 ns	±1.39 µs
20 kHz	±69 ns	±139 ns	±694 ns
92 kHz	±15 ns	±30 ns	±150 ns

Table1. Correlation between phase mismatch in degrees and mismatch in time at different input bandwidths

With a typical synchronization mismatch of ±25ns, GPS synchronization is still tight enough to solve all but the most stringent synchronization requirements.

Figure 12 illustrates how a system is being planned where this could be deployed with multiple microphone phased arrays to increase the size beyond 100 square meters.

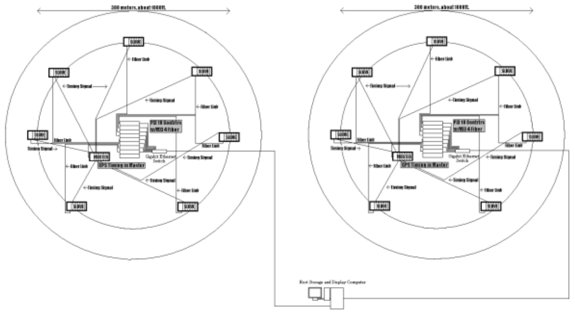

Figure 12: Distributed microphone arrays synchronized via GPS.

References

[1] J. Klos, R. Buehrle, “Vibro-Acoustic Response of Buildings Due to Sonic Boom Exposure: June 2006 Field Test.” NASA/TM-2007-214900, September 2007.

[2] Li, H.,Ou, J., Zhao, X., Zhou, W., Li, H. & Zhou, Z. “Structural Health Monitoring System for the Shandong Binzhou Yellow River Highway Bridge,” Computer Aided Civil and Infrastructure Engineering 21 (2006) 306 – 317.