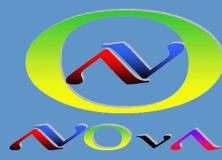




The NOvA Timing System

A system for synchronizing a long baseline neutrino Experiment

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Abstract: The NOvA experiment is designed to measure key parameters in neutrino physics related to the neutrino mass hierarchy and the asymmetry between matter and anti-matter. To make these measurements the NOvA experiment must correlate the extraction of beam to the NuMI target with individual hits in both a near detector and a far detector located 810 km from Fermilab. Precisely correlating hits across these detectors and reconstructing particle trajectories require that all of the readout electronics be precisely synchronized to an absolute "wall time" with a channel variation less than 15.2 ns. The NOvA Timing Distribution System accomplishes this through an integration of commercial GPS receiver technology and custom electronics. This paper describes the timing system, its component hardware and the synchronization method that is employed by it.

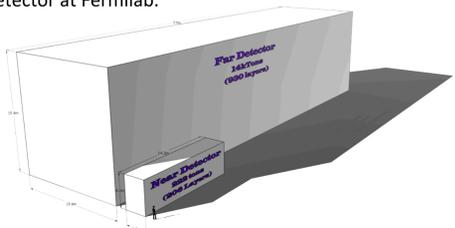
Nova Overview

The NOvA experiment is designed to probe the oscillations of neutrinos and anti-neutrinos to determine the transition probabilities for:

$$\nu_\mu \rightarrow \nu_e \text{ and } \bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

These transition rates will allow NOvA to determine the neutrino mass hierarchy and highly constrain the CP violating phase δ . The NOvA measurements will improve our understanding of the mixing angles θ_{13} and θ_{23} .

To perform these measurements NOvA has been designed with a 15kTon far detector which is located 810 km away from Fermilab and a small near detector at Fermilab.



This enormous detector with over 360,000 channels of synchronized readout electronics which operate in a free-running continuous readout mode. All of these channels are additionally synchronized with an absolute time to the beam systems at Fermilab, allowing NOvA to know precisely which interactions in the detector are from neutrinos that came from Fermilab.

The NOvA Timing System is the Key Component that make this possible



NOvA Laboratory at Ash River, MN



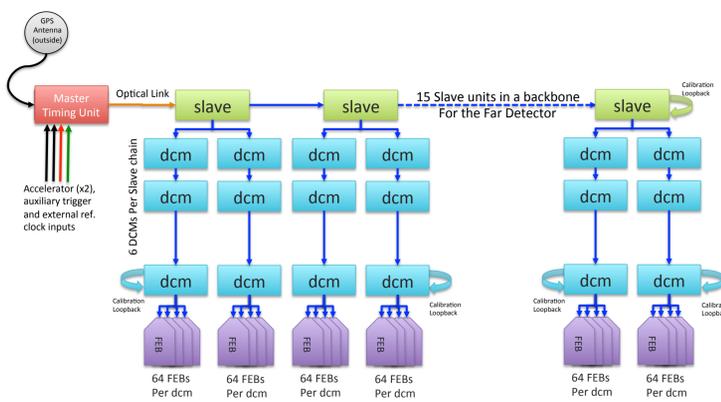
The 700kW NuMI beam line sends neutrinos to the NOvA detector at Ash River at an angle of 14 mrad to the beam axis.



The NOvA Integration Prototype Near Detector began operating in November 2010 using the timing system to synchronize 11 data concentrator modules and 12000 channels of readout electronics. The detector collects data on both the NuMI and BoONE beams at FNAL.

Timing System Topology

The NOvA timing system is arranged hierarchically, linking a single master with a backbone system of 15 slave modules (1 per kiloton of detector) which fan out to interconnect the custom designed Data Concentrator Modules (DCMs) that aggregate data from sets of 64 front end boards which in turn readout the avalanche photodiodes that are connected to the fiber optic readouts of 32 detector cells.



Timing information is propagated through this network over a custom LVDs timing link which provides a master clock line, a uni-directional serial command channel, a dedicated SYNC pulse line and a loopback SYNC reflection line.

This topology allows all 368,640 channels of the far detector to be communicated to in parallel using for issuing system wide timing and diagnostic commands, as well as permitting individual commands to be addressed to specific devices in the chain through a simple address scheme. In addition, each device in timing chain has a timing circuit, implemented its embedded FPGA, that allows for a programmable delay buffer. This delay buffer is calibrated through the SYNC loopback reflection lines to determine the exact timing offset to the next unit in the chain. Allows all of the delay buffers to be set to control the delivery of the SYNC pulses to occur system wide on a specific (deterministic) clock cycle, and permits the entire system to be universally synchronized.



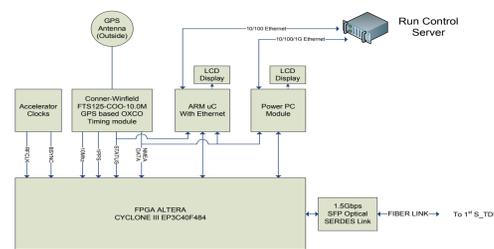
NOvA timing system installed at Ash River

Timing System Masters



The timing distribution Master units are responsible for:

- Locking the master clocks to a GPS receiver
- Establishing a universal **NOvA Time** from the GPS data
- Decoding the FNAL accelerator signals and tagging them with **NOvA Time**
- Generating the master clocks that drive the data acquisition hardware.
- Generating the system wide synchronization command sequences and master SYNC signals
- Executing a spill server application that interacts with the NOvA DAQ system and provides beam trigger decisions



The Master TDU mates a Conner-Winfield high precision oven-controlled GPS receiver unit with an Altera FPGA running the NOvA timing/sync firmware. This system provides auxiliary inputs for FNAL accelerator signals as well as for arbitrary NIM and TTL inputs for performing external event triggering. The MTDU can be accessed from either an ARM microcontroller with an Ethernet command interface layer or from a custom designed PowerPC single board computer which attaches as a daughter board to the TDU base board. The daughter board runs a full featured embedded Linux LCD displays are provide on the front face of the unit to provide diagnostics and book

NOvA Time

NOvA uses an optimized high resolution time stamp system to tell time. We synchronize and align our time stamps to the universal time of the GPS 1 pps signal. The time stamps are simple 56bit wide integers that keep time starting from Jan 1, 2010 at 00:00:00.

The NOvA clock is designed to "tick" at a maximum of 64MHz for the time stamping of detector hits and accelerator event. The time stamps were split into high and low words to optimize the operation of the custom frontend electronics and to permit higher efficiency in packing the hit data for events.



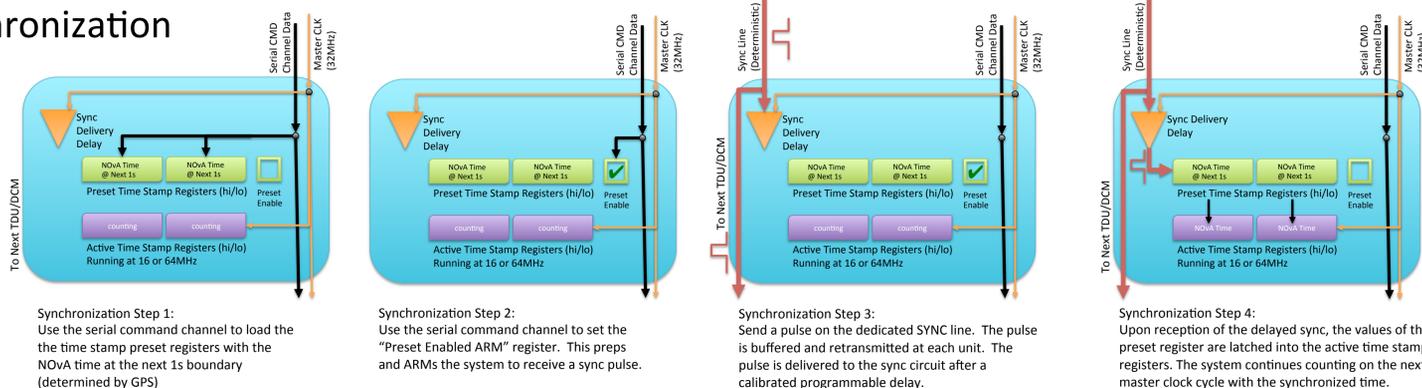
The timing system and time format are upgradable to support sampling frequencies of above 1GHz to perform specialized timing calibrations and time of flight measurements.

This system gives NOvA the ability to tell the absolute wall time without any loss of precision for over 35.7 years.

NOvA Synchronization

NOvA uses an: **"At the tone the time will be..."** method for detector synchronization.

Devices are loaded with a time in the future determined by GPS and then set the time when a SYNC is received.



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