Beam Synchronous for the Rest of Us!

RF-locked serial protocol doesn't have to be the end-all-be-all.

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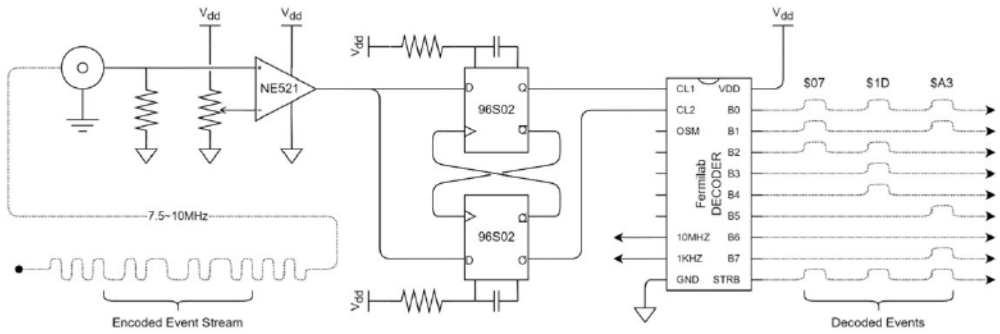
Overview

Fermilab's Tevatron Clock (TCLK) has been an integral part of the accelerator control network since the 1980's. This protocol has enabled flexible, real-time event distribution for thousands of devices across campus.

Forthcoming upgrades to the Fermilab complex (PIP-II, LBNF, ACORN) demand higher levels of precision to maintain inter-bunch timing for Instrumentation and Control applications. This poster presents a method to distribute beam-synchronous events via asynchronous serial protocols by integrating local LLRF and global PPS signals.

Background

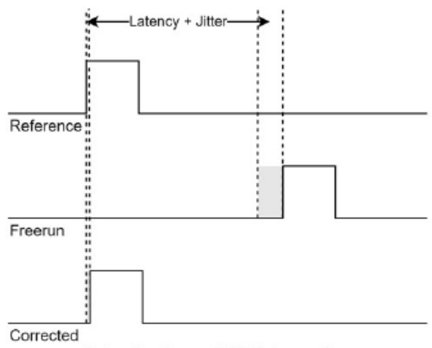
TCLK is the 10Mhz "Modified Manchester" serial protocol that governs most functionality of Fermilab's systems. Encoding and decoding of this protocol was originally accomplished through discrete logic circuits, allowing for the carrier frequency to move with the machine's RF. Today TCLK is primarily decoded by FPGAs, which while faster, introduce more rigidity in the Serial/ Deserialization process.



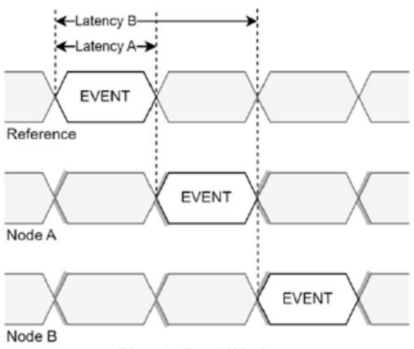
Original TCLK Decoder showing the use of the custom Fermilab IC

New Concepts

The best part about late-stage modernization is the groundwork that has been laid by others. In addition to planned data packet capabilities, this proposal offers two new concepts for Fermilab's timing system: a Pulse Per Second (PPS) global reference provided via White Rabbit, and packet framing via Event Windows (EW). PPS allows for downstream systems to orient themselves to a grandmaster source. Event Windows are a method for discretizing time, allowing actions to play out reliably at an exact instant.



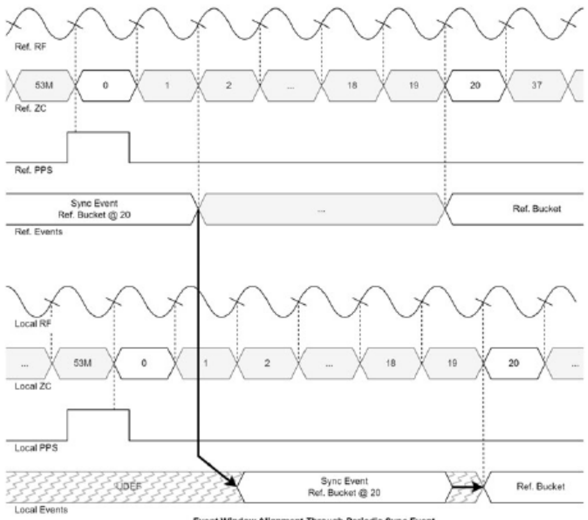
Pulse Per Second (PPS) Correction



Discrete Event Windows

RF Alignment Through Periodic Sync

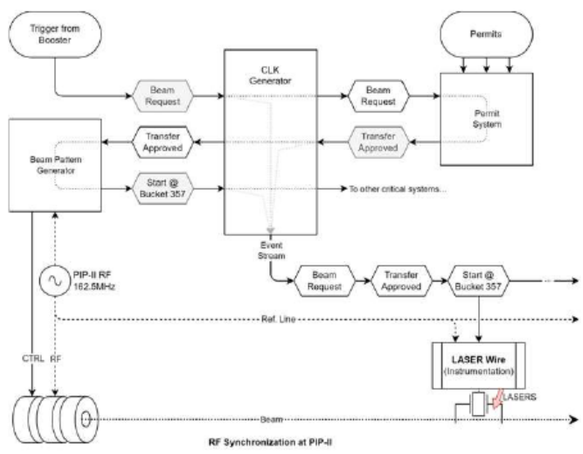
Given the preceding concepts, two nodes on Fermilab's timing network can align themselves by counting LLRF Zero Crossings (ZC) relative to the PPS. A sync event is broadcast to reset downstream systems at an exact bucket. This bucket acts as the reference bucket for all subsequent events. Timing is now relative to the RF, not delays or the speed at which events are encoded/decoded.



Event Window Alignment Through Periodic Sync Event

Application to Modern Systems

This approach may be readily applied to Beam Synchronous (BS) systems at PIP-II. Utilizing the data field, the Beam Pattern Generator (BPG) may inject a pre-trigger event containing the exact bucket at which beam will play out. Downstream systems consume this event and trigger with an offset proportional to the Time of Flight (ToF) or phase delay from the source. This solution may also be applied to sweeping RF systems, allowing for general serial protocols to execute any number of BS functions across machines.



RF Synchronization at PIP-II

Acknowledgements

This document utilizes concepts from both the GSI/FAIR and LCLS-II timing system upgrades. It is based heavily on prior work for the PIP-II LCLK timing system as documented by Mark Austin, Dan Mcarthur, and Greg Vogel.

PIP-II ACORN