Low Cost Timing System for High Precision Particle Detection

SLAC NATIONAL ACCELERATOR LABORATORY

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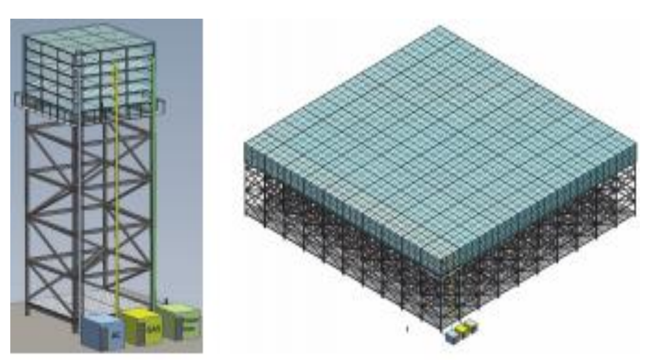
Background

- High-speed timing systems are the key component of any particle accelerator. However, while many precision timing systems can perform the task, they are often expensive. Projects like CERN's Mathusla detector need thousands of timing systems and would require a substantial budget if current price detectors are used. Therefore, it is necessary to develop a low-cost precision timing system from commercially available parts.
- To detect the path of rare particles, layers of detectors will be constructed on top of the experimentation site. The points at which the particle interacted with the detector are timed and then used to map its path. (See diagrams)



Lubatti, Henry. *LOI for Simons Foundation Target Grant in MPS: The MATHUSLA Demonstrator.* University of Washington,

Overview

Objective:

The purpose of this project is to make a prototype of a high precision timing system using low-cost industrial parts. If successful, the system would read pulses with the precision of at least 50 picoseconds. It will be replicated to make thousands of devices that would be implemented in a large volume particle detector at CERN and other laboratories.

Model:

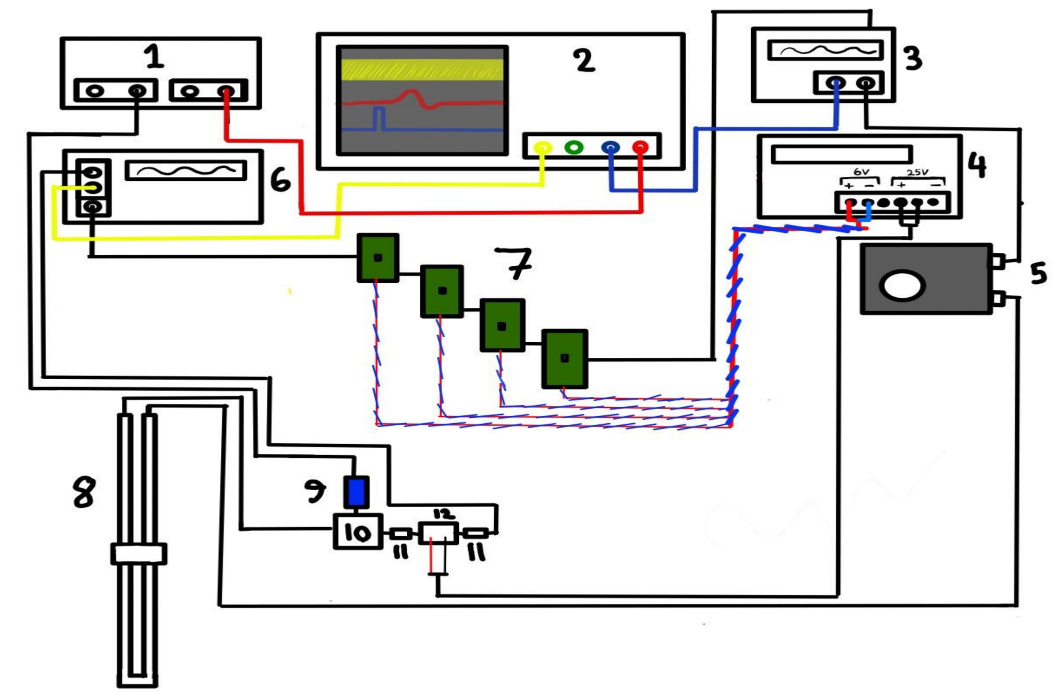
First, the pulse would be multiplied (mixed) together with a reference fast-paced clock signal to create a signal. For a rough measurement of this output signal, a counter in a microcontroller with the precision of 20 nanoseconds will be used. Then an additional circuit board or charging capacitor would get the timing down to 1 nanosecond. Lastly, an ADC will be used to accurately time the signal to 50 picoseconds. Most of this project concentrated on reading and testing the most precise timing method.

Method:

1.Simulate and mix an external pulse with low-cost parts to see if it creates a readable signal.

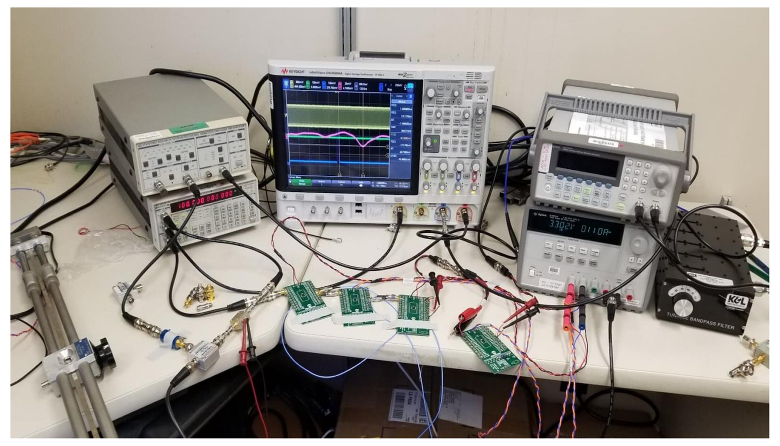
2.Find and program an ADC that could be externally triggered by the pulse, take in an external clock, and take a burst of samples from the mixed signal (to be fitted to a curve).

Experimental Setup



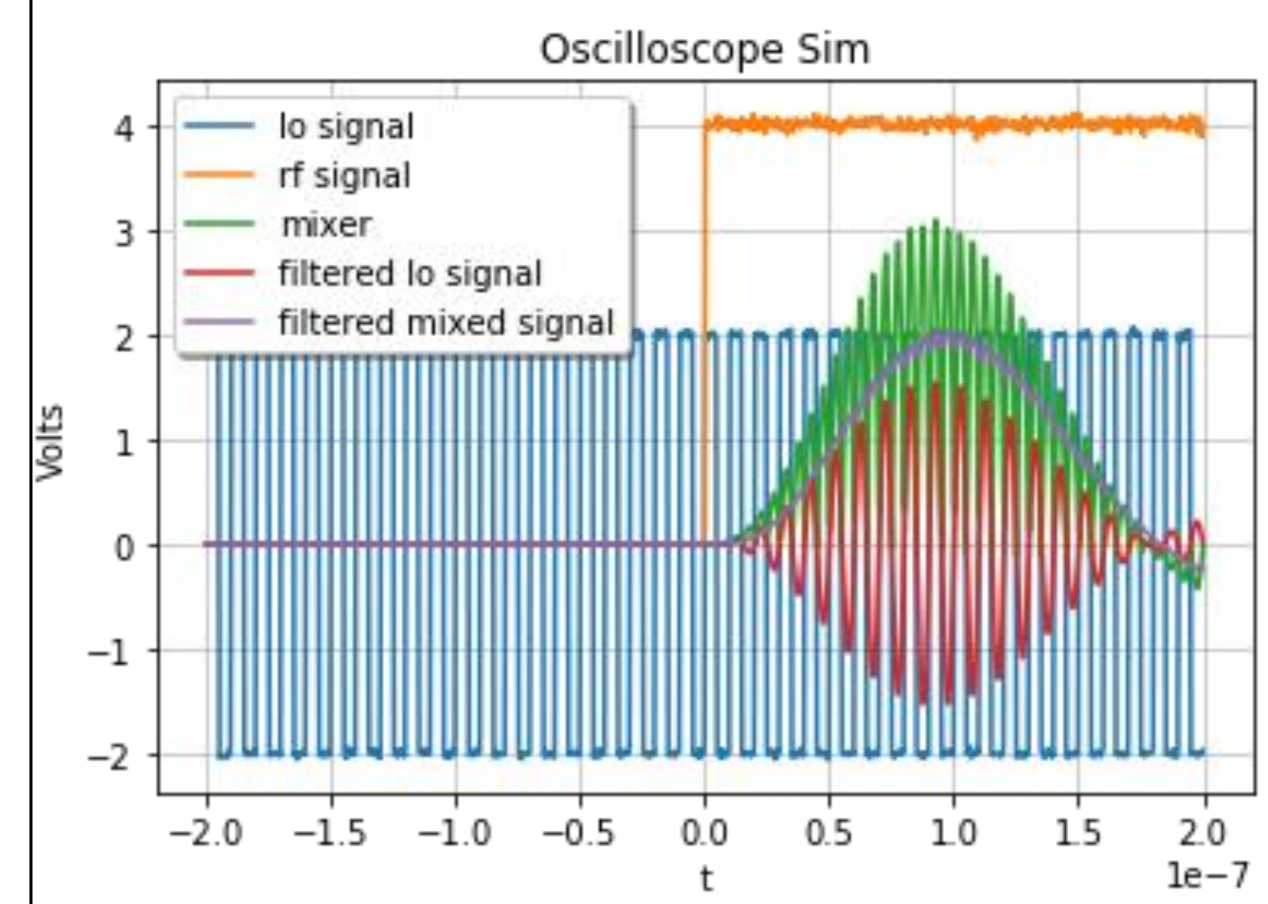
1. Low Noise Preamplifier
2. Oscilloscope
3. Waveform Generator, triggered by divided signal
4. Power Supply
5. Tunable Bandpass Filter
6. Clock Generator, set at 100 MHz
7. Dividers
8. Trombone
9. Low Pass Filter
10. Mixer
11. 10 Hz Attenuator
12. Coaxial Amplifier

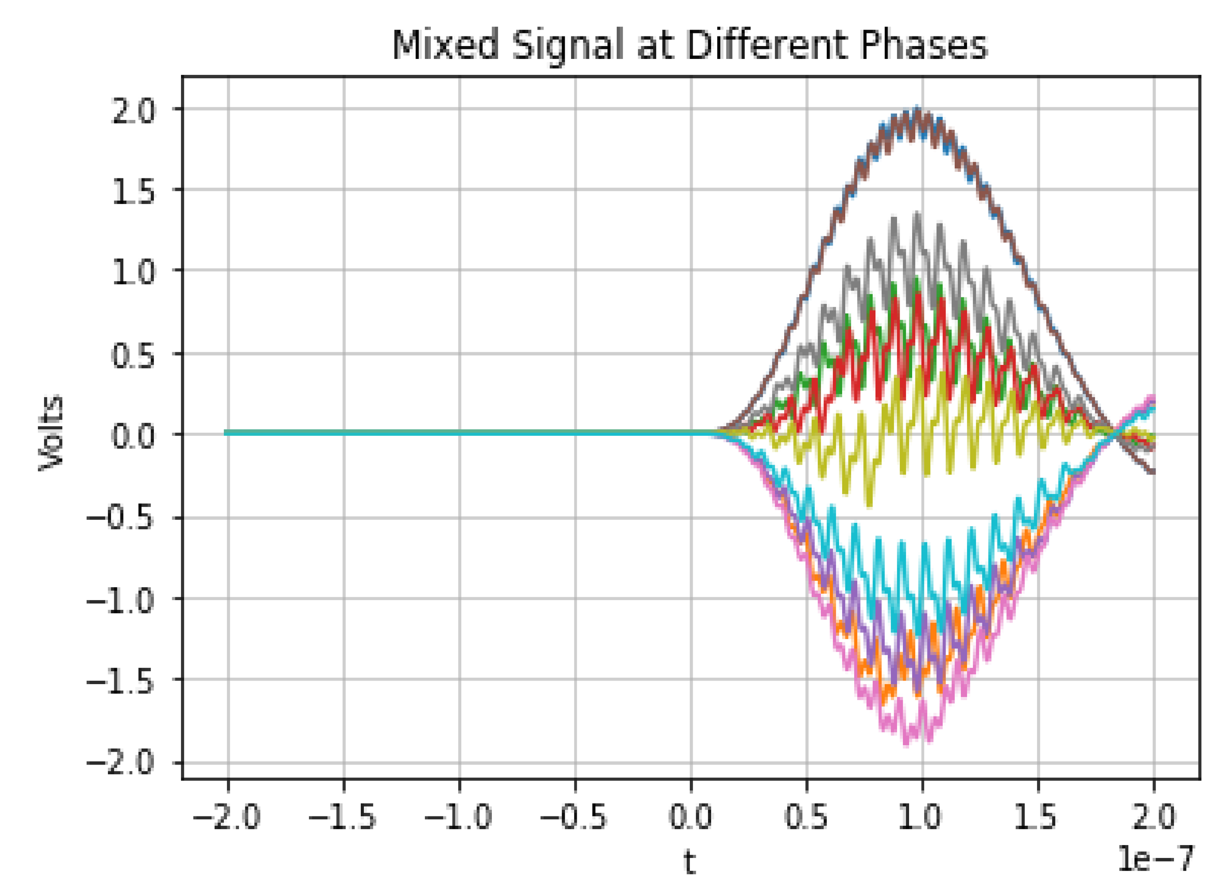
Pulse Mixing Prototype



To create a mixed signal, a fast clock signal needs to be mixed with an external pulse. The fast clock signal comes directly from a clock generator that is set to output a 100 MHz signal. The pulse is created by dividing the fast signal by four 4-bit counters by 2^{16}, which triggers a waveform generator generating a pulse. The pulse goes through a tunable bandpass filter to transform the pulse into a ringing sine wave (for better results from the mixer), and then a trombone to test the sensitivity of the mixed signal to pulse delay. Lastly, both signals are then mixed, put through an 11 MHz low pass filter and a preamplifier for readability, and are then displayed on the oscilloscope.

Simulation Results





A simulation in python was done of the experimental setup, substituting the fast pulse with a square wave. Random noise was added to both rf and lo signals to mimic the oscilloscope. The simulation showed that amplitude should vary with phase offset.

ADC Testing

Two microcontrollers (TI MSP432P4111 and Microchip PIC32MX795F512L) were programmed to enable their ADCs to read and convert the analog inputs upon the detection of a signal. Since the incoming pulse is at high speed, the ADC must be triggered by hardware to take a burst of samples. These samples are then fitted to a function that could determine the signal's shape and peak value.

Results

Pulse Mixing: The 100 MHz clock was successfully mixed with a divided signal with an average precision of 72 picoseconds. Using a two-output set up an average precision of 42 picoseconds was reached.
Microchip: LED's delay response to a change in resistance shows the ADC conversion with an external trigger. Printing the results of the ADC proved to be difficult.
Texas Instrument: Read and printed the ADC's conversion of an external voltage source at a hundred thousand samples per second. External hardware triggering however, proved to be difficult.

Conclusions

Problems:

- The mixed signal was readable, but there is noticeable timing jitter.
- Could not find a way to both get a readout and externally hardware trigger the ADC.

Improvements:

- Research and implement a different microchip
- Design and test the system for timing to ~20 nanoseconds, then 1 nanosecond.
- Trigger ADC using an external source
- Use evaluation boards more suitable to high frequency signals.
- A two-output mixed signal was set up along with a replacement 14-bit counter instead of four 4-bit counters. At first glance the second system seemed to perform better. However, more testing needed to be done with this setup.

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