PIPII laserwire Laser System design

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PIP-II Beam Instrumentation Design

Laser Wire final Review

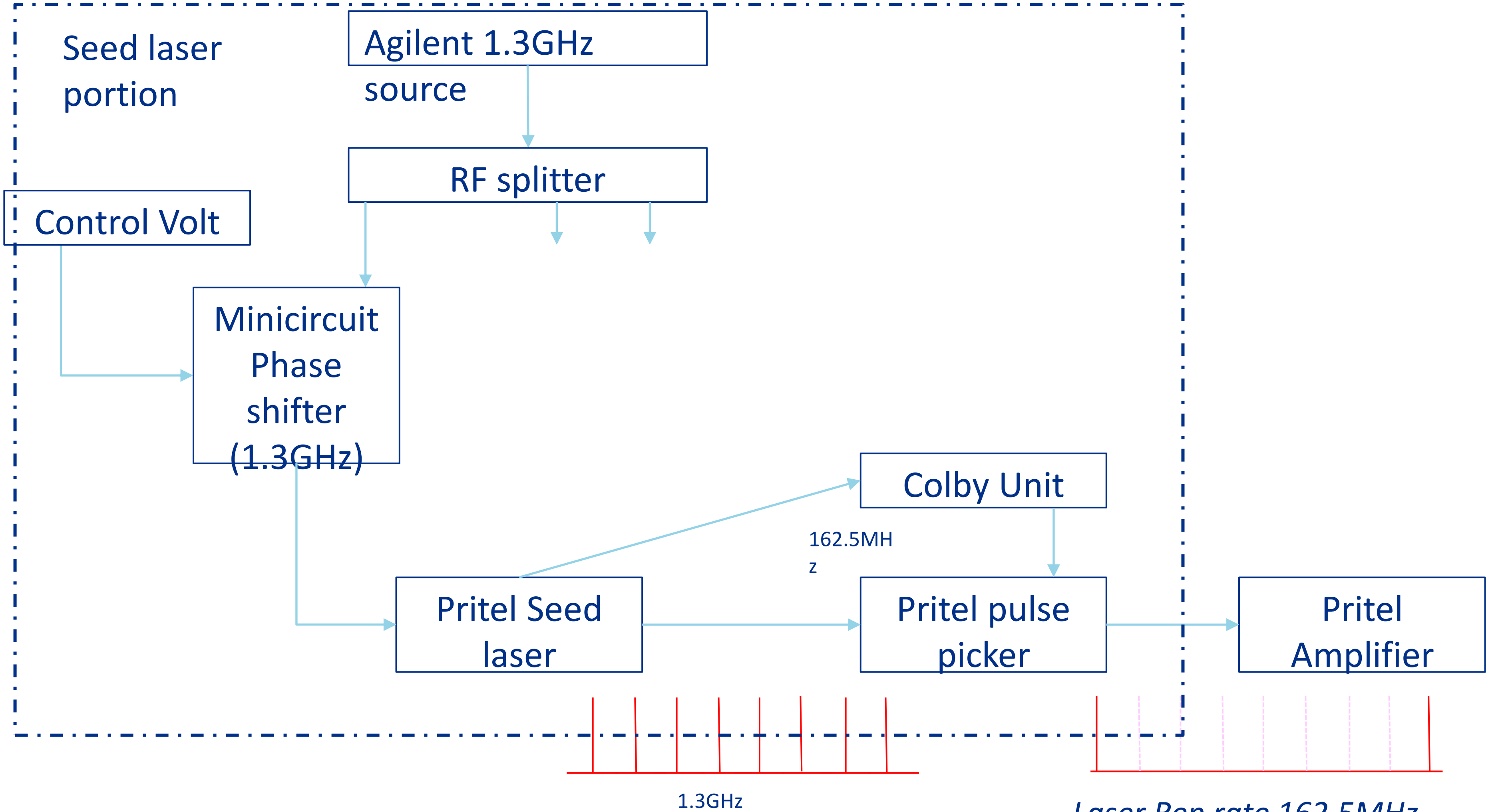
May. 7, 2024

A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Outline

- PIPII-IT laser system
- Pros and cons
- PIPII laser system redesign
  - Fiber portion
  - Free space portion
- Conclusion

PIPII-IT laser system



Laser Rep rate 162.5MHz
Output Power 6nJ/pulse

What we learned from PIPII-IT experience

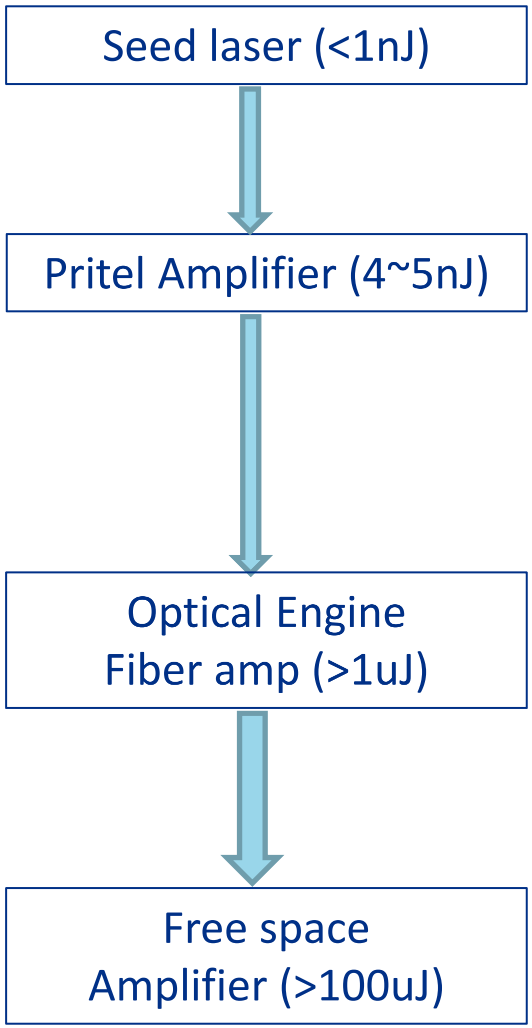
- Pros
  - Very reliable system turn-key operation for most of the time
  - Be able to measure both spatial and temporal measurement
  - Simple transport system
- Cons
  - Need multiple seed/amplifier system will increase the cost dramatically
  - Only one pulse length available
  - Power is limited
    - Low signal to noise ratio
    - Lock-in technique helped a little bit but still very low signal to noise ratio
  - Very limited flexibility for future upgrade

What we want for PIPII

- Enough power to get good signal noise ratio
- Flexibility in terms of the pulse duration
  - optimize laser pulse overlap with H- beam pulses
- Flexibility in terms of the future upgrade option
- Lower the cost if possible

Fiber laser-free space laser hybrid system

PIPII laser option (hybrid version)

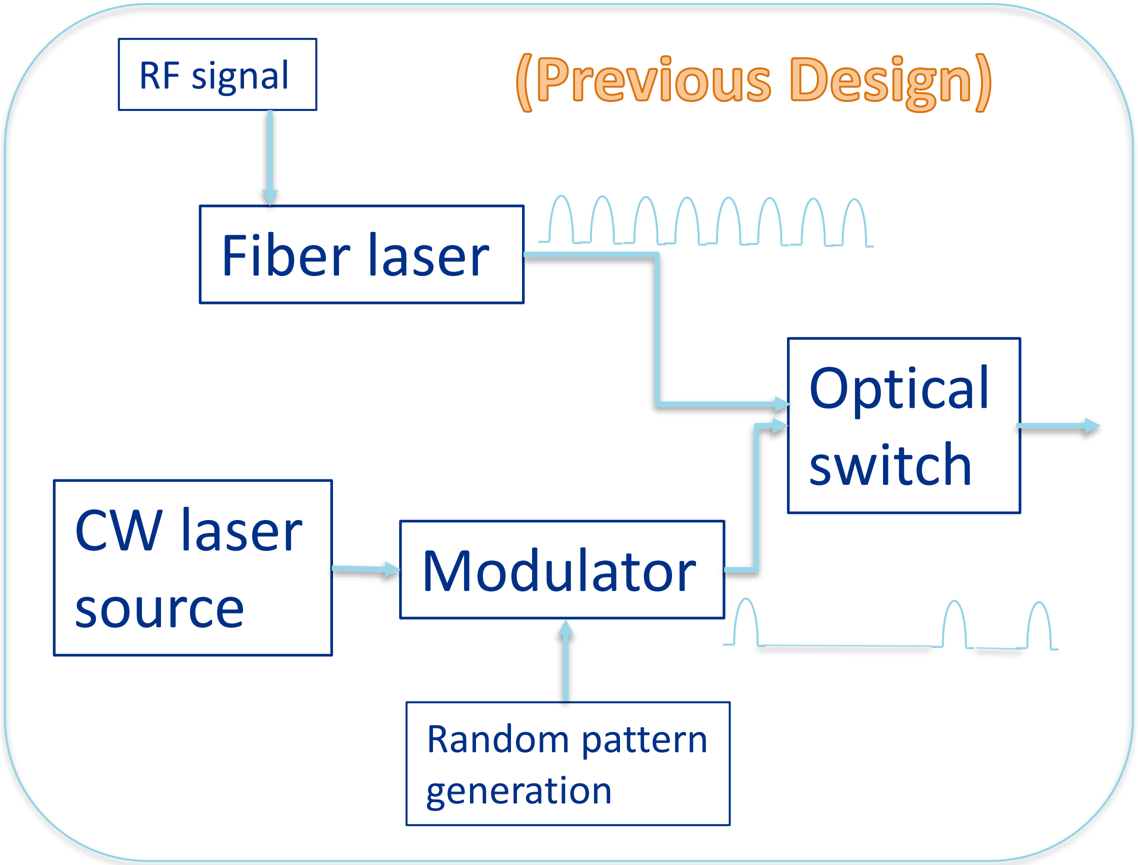


- Requirement
  - Wavelength between 1030nm and 1070nm. We’re using 1064nm.
  - Pulse width: at least 2 options
    - 2-3ps and 100ps FWHM
  - Pattern: Programable
  - Turn-key system
  - Final energy: 100uJ at 10MHz,(about 10 µs long) the higher the better
    - Depends on signal-to-noise and total power on windows
  - Max power of 150mJ/cm2 per 10 µs on optical windows
    - Only transport laser light while making beam measurements

Seed laser option

- Short pulse
  - Use PIPII-IT version pulse width 3-4ps(FWHM)
  - Specified design for longitudinal measurement
  - Fiber based pulse picker to get pattern if needed
- Long pulse
  - Implement design developed by Dave & Todd for Fermilab linac laser notcher
  - Start with CW source
  - Use modulator to pick up the pattern we wanted aiming for 100ps FWHM but programable from 50ps to 200ps FWHM

PIP-II – The Timing Problem for x/y-Spatial Measurements



- PIP-II will have a pseudo-random pulses down the linac
- Original plan required an optical switch to modulate a Master Oscillator (MO)
- Drawbacks
  - Phase drift from laser and pattern
  - EOM extinction only 20db
- Solution:

Let's simplify the driver!

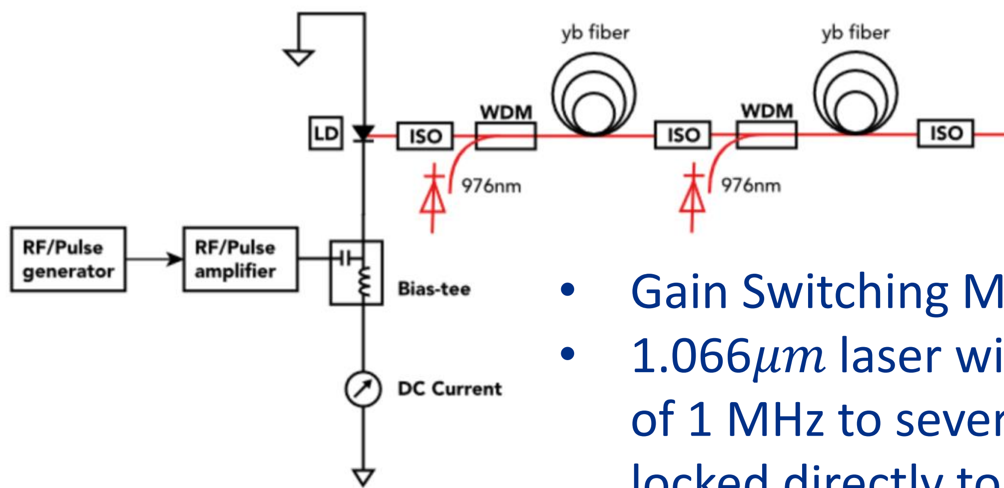
Long seed pulse generation

- Concept

A Versatile and Highly Reliable Green-light Drive Laser for High Current Photoinjectors

S. Zhang†

Jefferson Laboratory, 12000 Jefferson Avenue, Newport News, Virginia, 23692, USA



- Gain Switching MOPA for SHG
- 1.066μm laser with rep-rate of 1 MHz to several GHz locked directly to RF clock
- Nominal pulse width 30-50ps

Long seed pulse generation

- Concept

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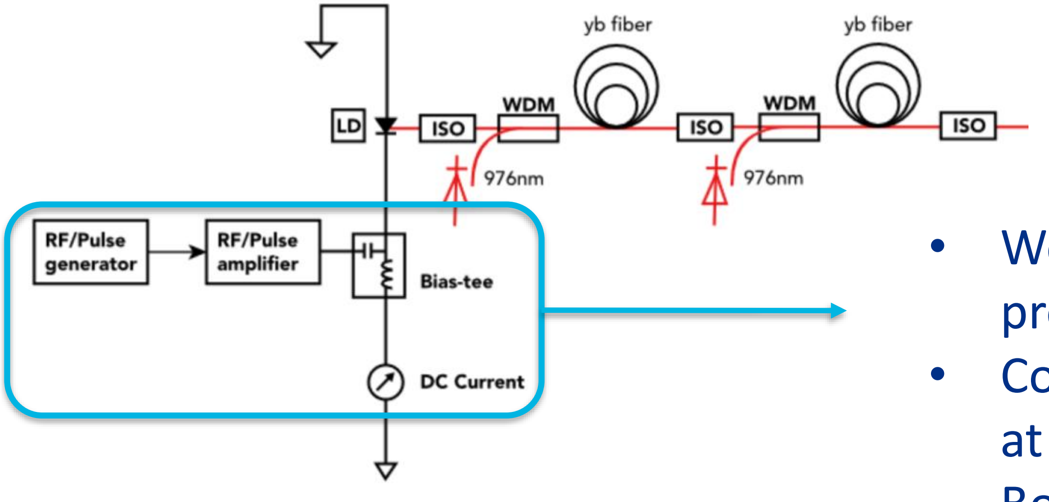
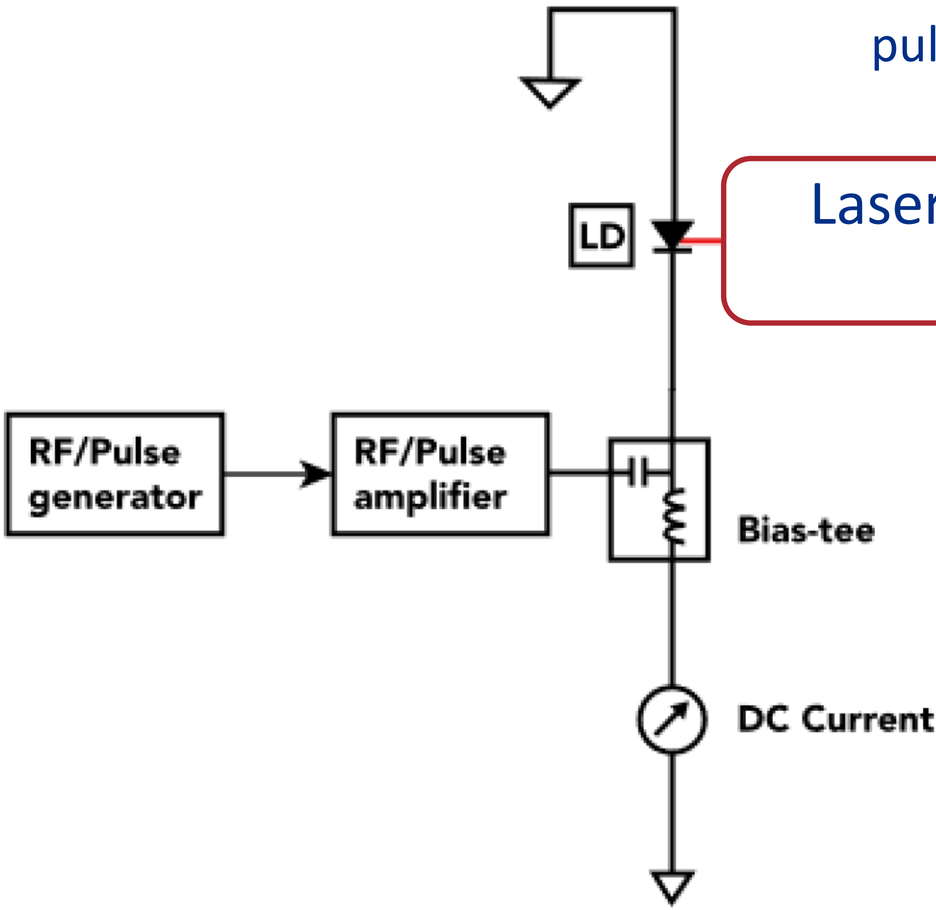


- We built two electronic driver prototypes last summer
- Completed preliminary tests at Fermilab, PriTel, Jlab, and Boston University

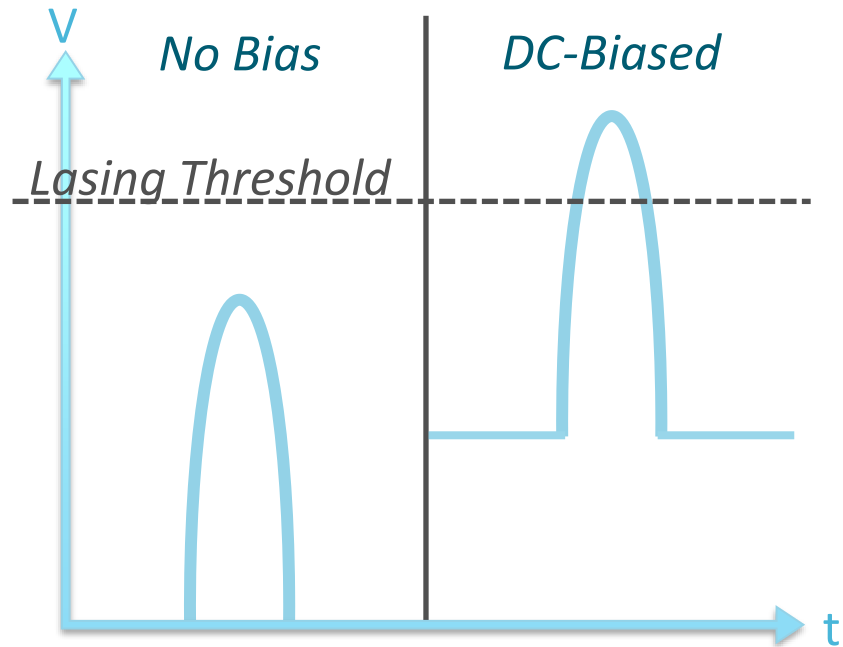
Long seed pulse generation

- Concept



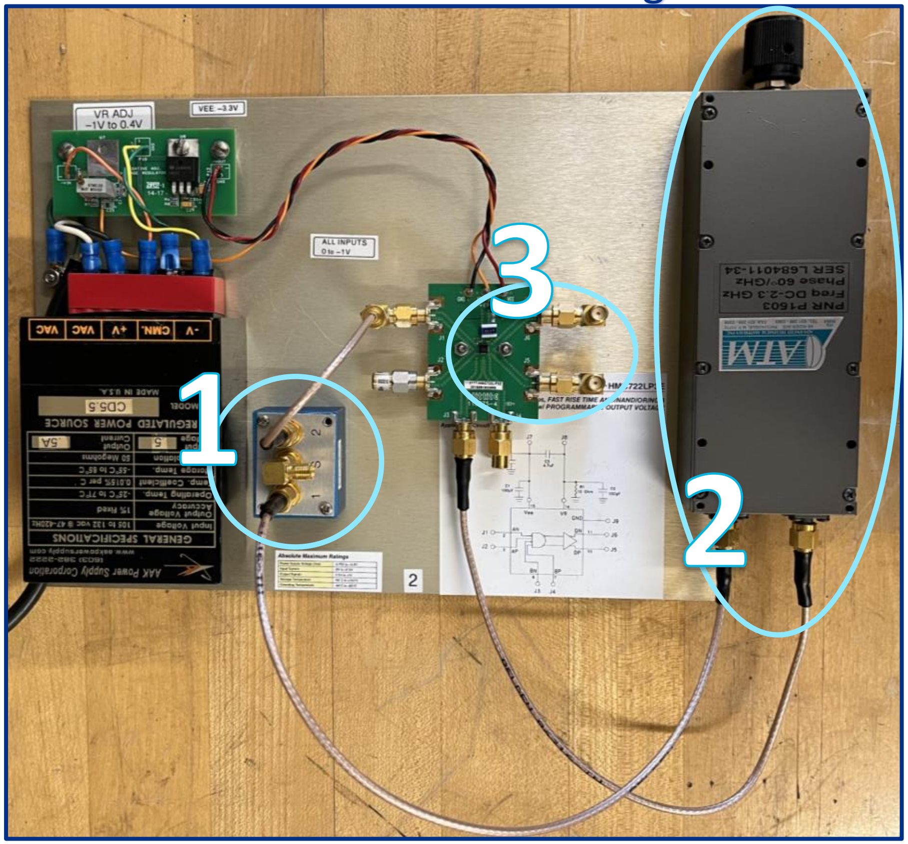
- Using a Diode laser we can decouple the pulse modulator via *Gain-switching*

Laser Amplification system



Electronic pulse generation

HMC722LP3E – Fast Rise Time Logic Gate



1. 50/50 RF Splitter
   - 1 V_{pp} input
   - Port S1 (50 $\mathrm{m}V_{pp}$) to phase delay
   - Port S2 (50 $\mathrm{m}V_{pp}$) to Fast NAND
2. DC-3.2 GHz Phase delay
   - Prototype 1 range of 75ps-250ps (FWHM)
   - Prototype 2 range of ~30ps-200ps (FWHM)
3. Fast NAND Gate
   - Output with complement

Two negative inputs triggers a pulse

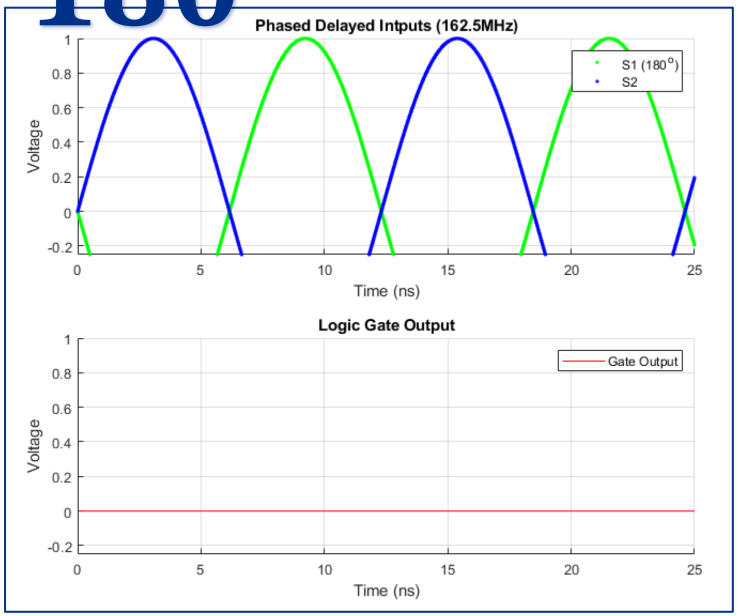
Rise-time ~20ps

Max output ~650 mV

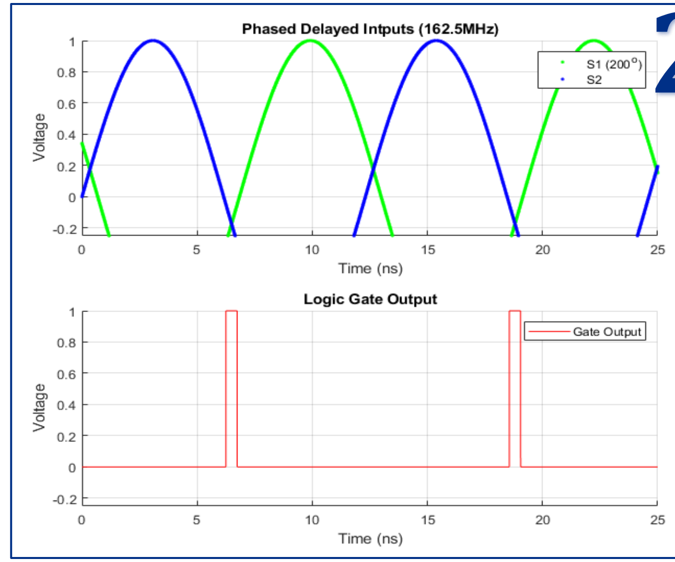
Electronic pulse generation

Logic gate MATLAB diagrams:

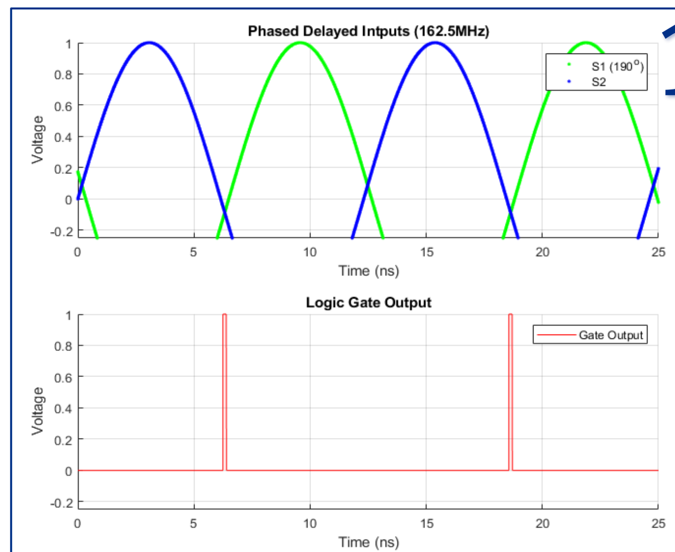
180°



200°



190°

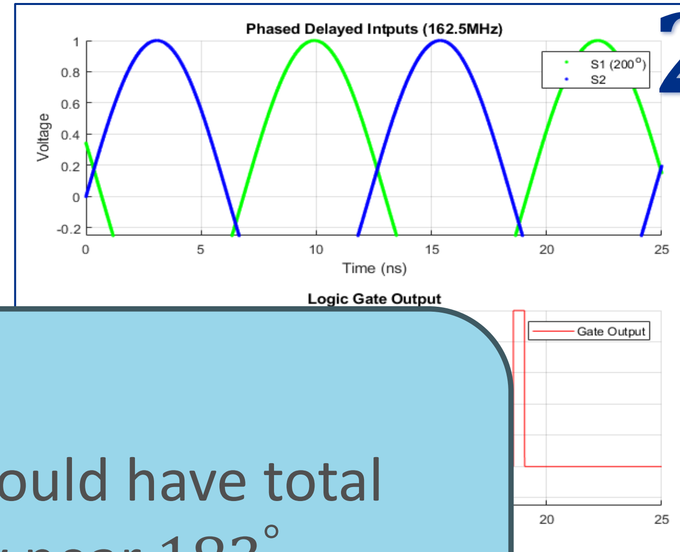


Assuming 50mV threshold and instantaneous rise time for logic gate

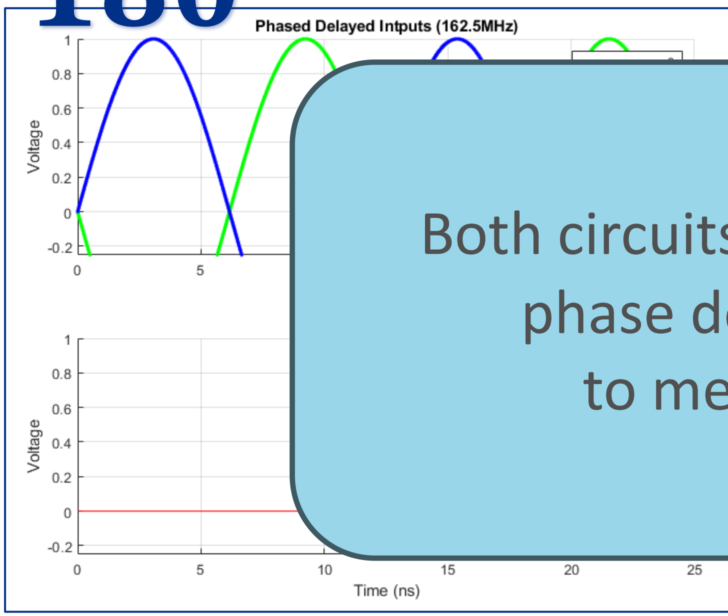
Electronic pulse generation

Logic gate MATLAB diagrams:

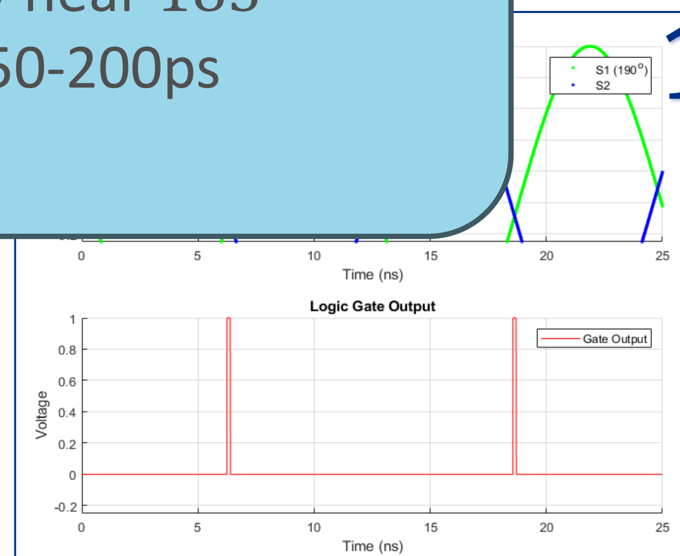
200°



180°



190°

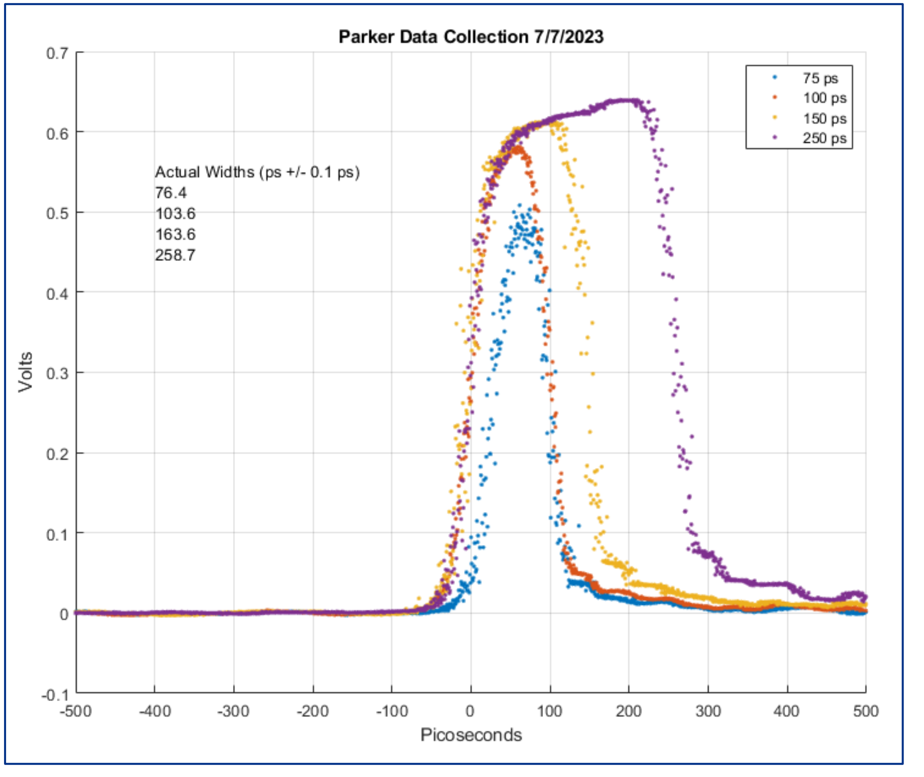


Both circuits should have total phase delay near 183° to meet 50-200ps

Assuming 50mV threshold and instantaneous rise time for logic gate

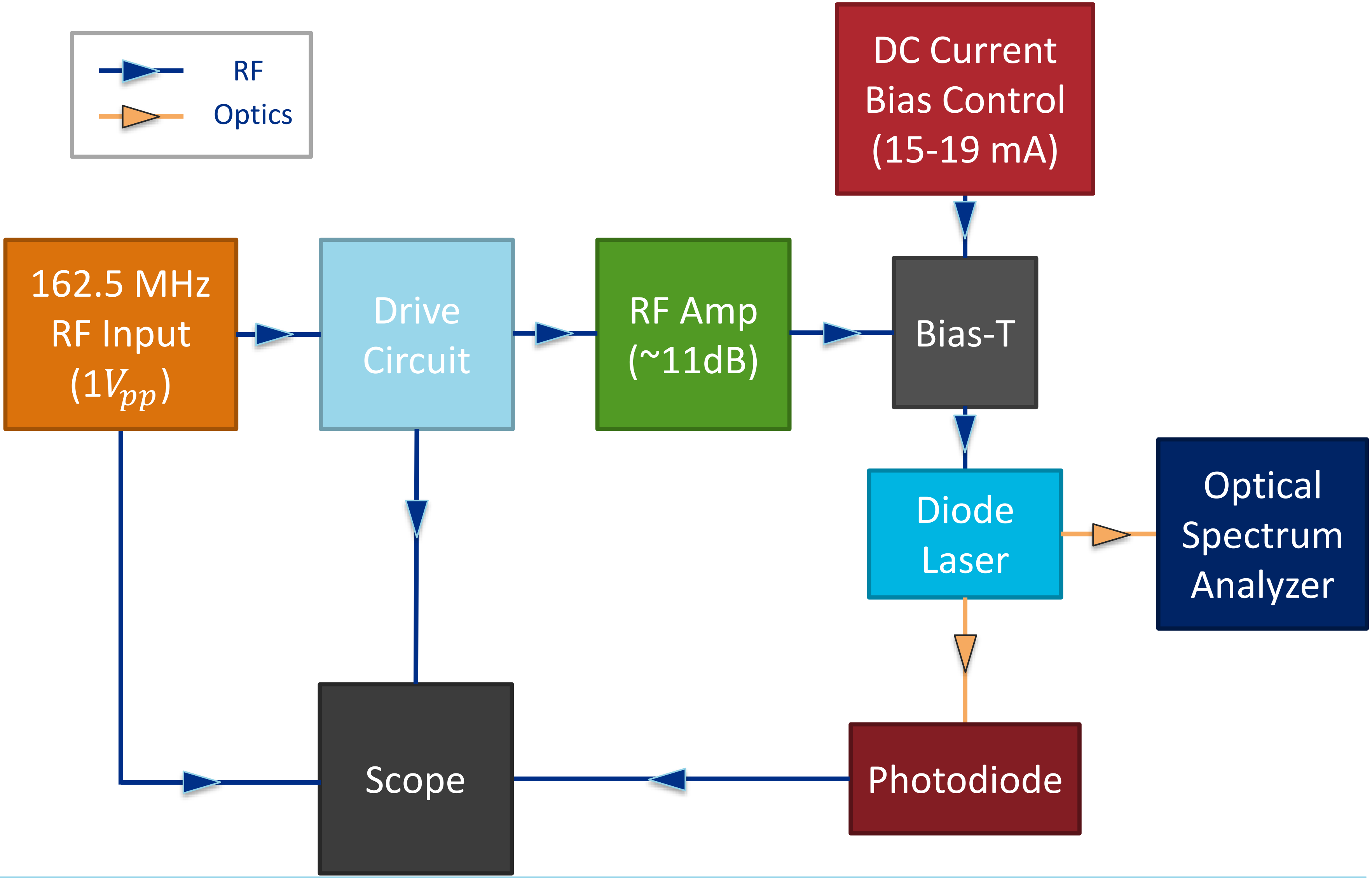
Electronic pulse generation

Electronic Pulse (Not Amplified)

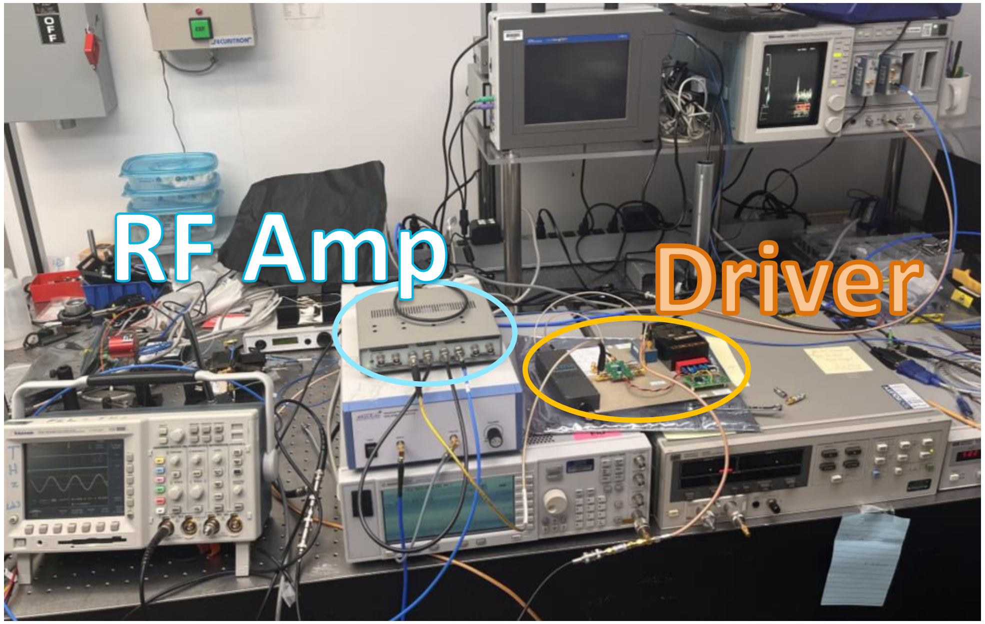


Measured at Fermilab: Infiniium DCA 86100A Wide-Bandwidth Oscilloscope

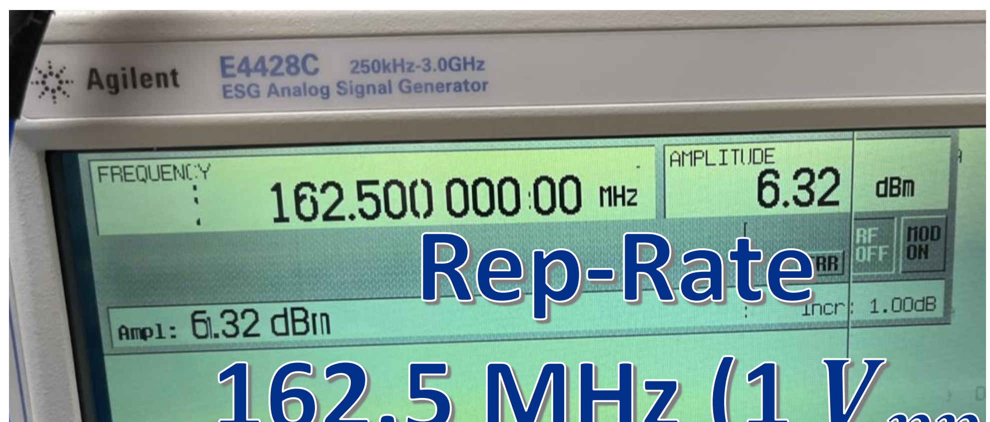
Drive System Test Block Diagram – Jlab Tests



Results from Jlab

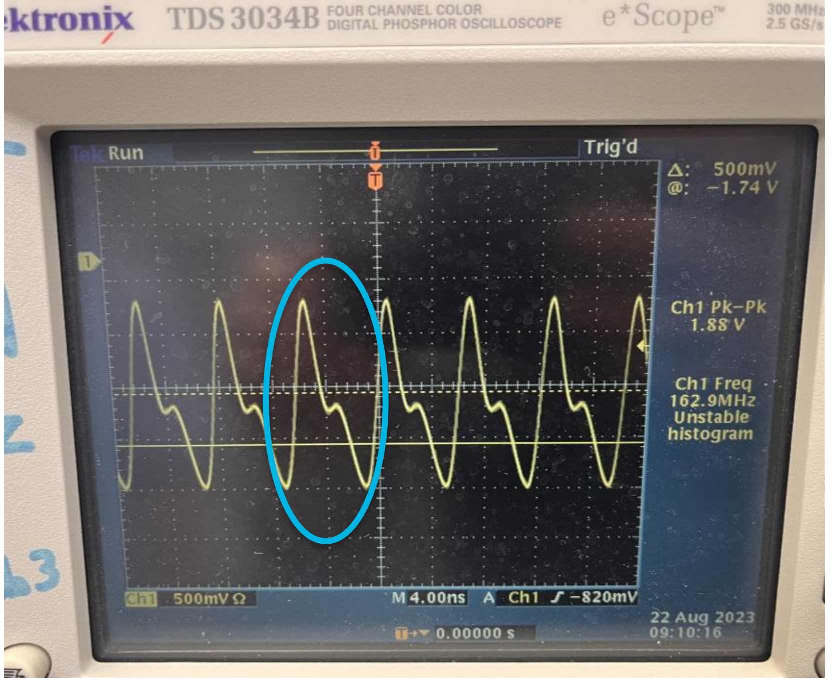


- Limited setup at Jlab
- Borrowed RF amp (DC-300MhZ)
  - Limited our rise-time ~1 ns and added ringdown
  - Shortest electric pulse ~4ns



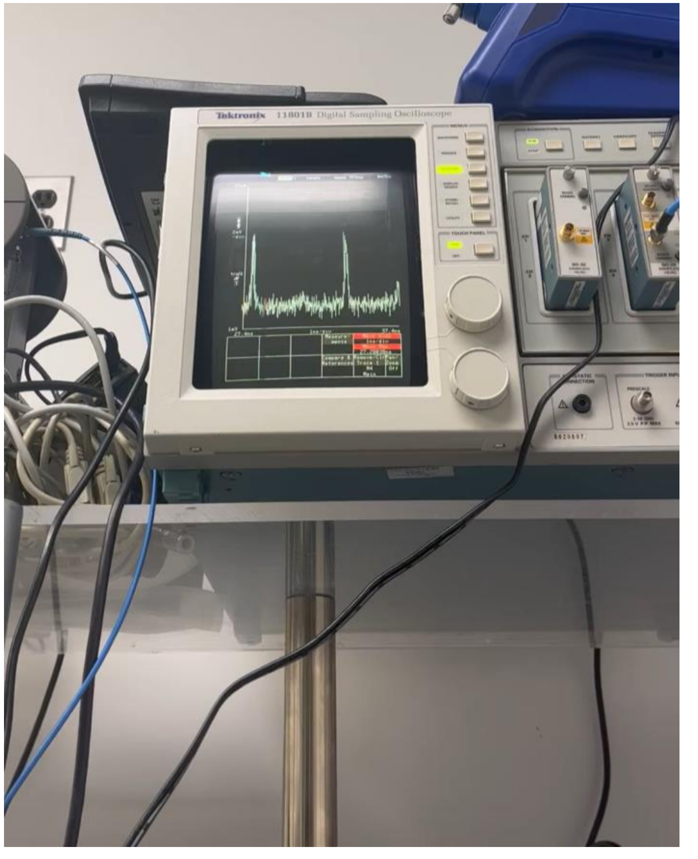
Results from Jlab

Electronic Signal



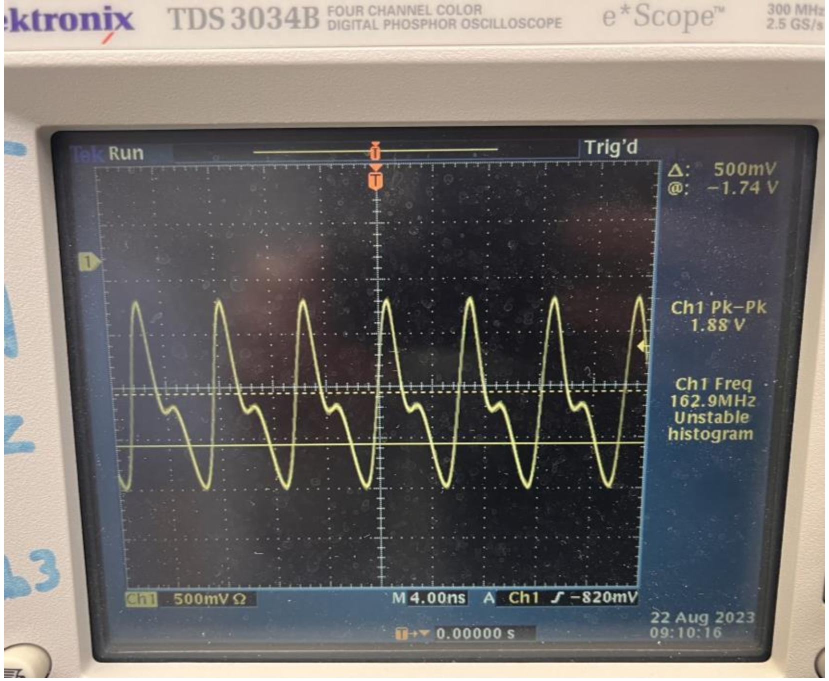
Not the best input, but DC-bias alleviates ringing

Optical Signal

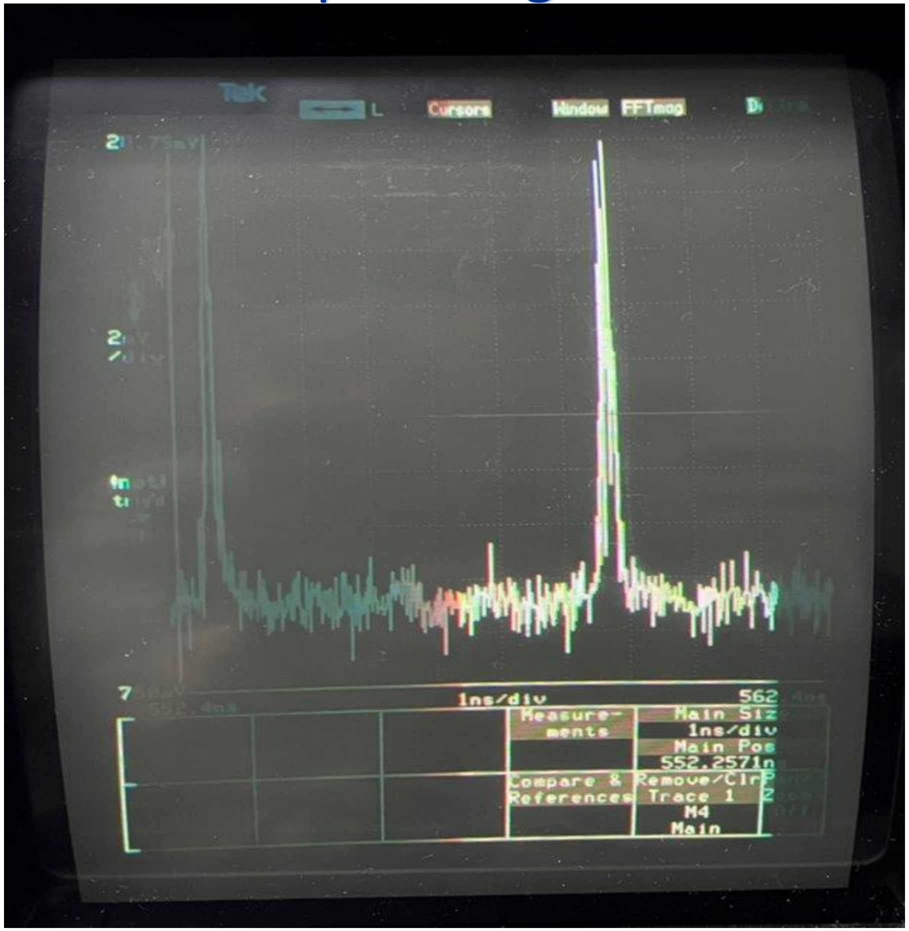


Results from Jlab

Electronic Signal



Optical Signal



*With added a DC-bias of ~17 mA

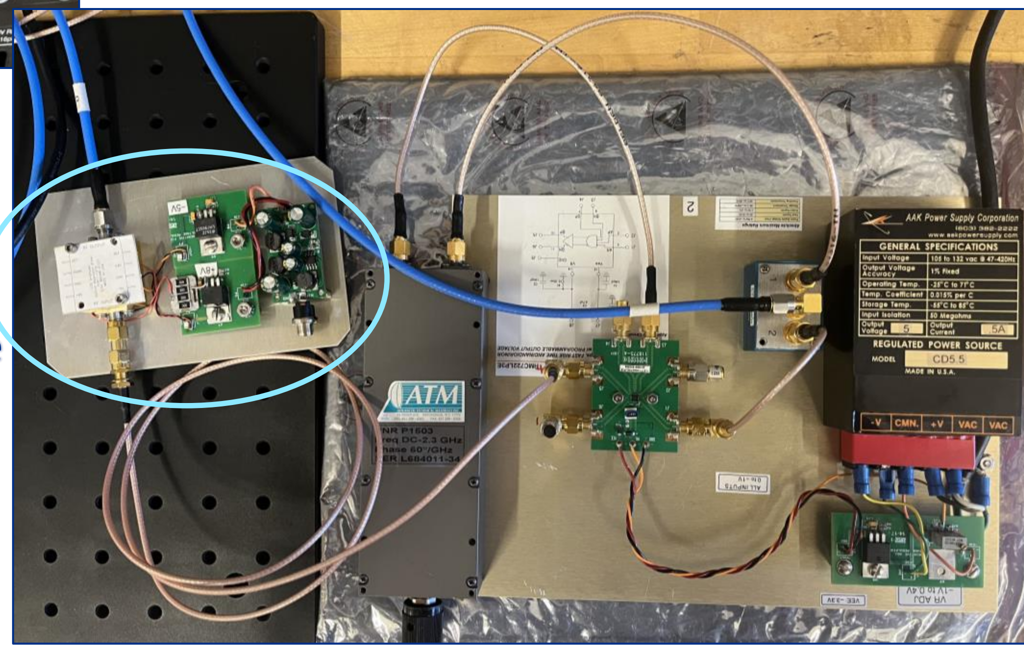
FWHM ~200ps

Results from BU

Electronic Signal
(350 ps FWHM)

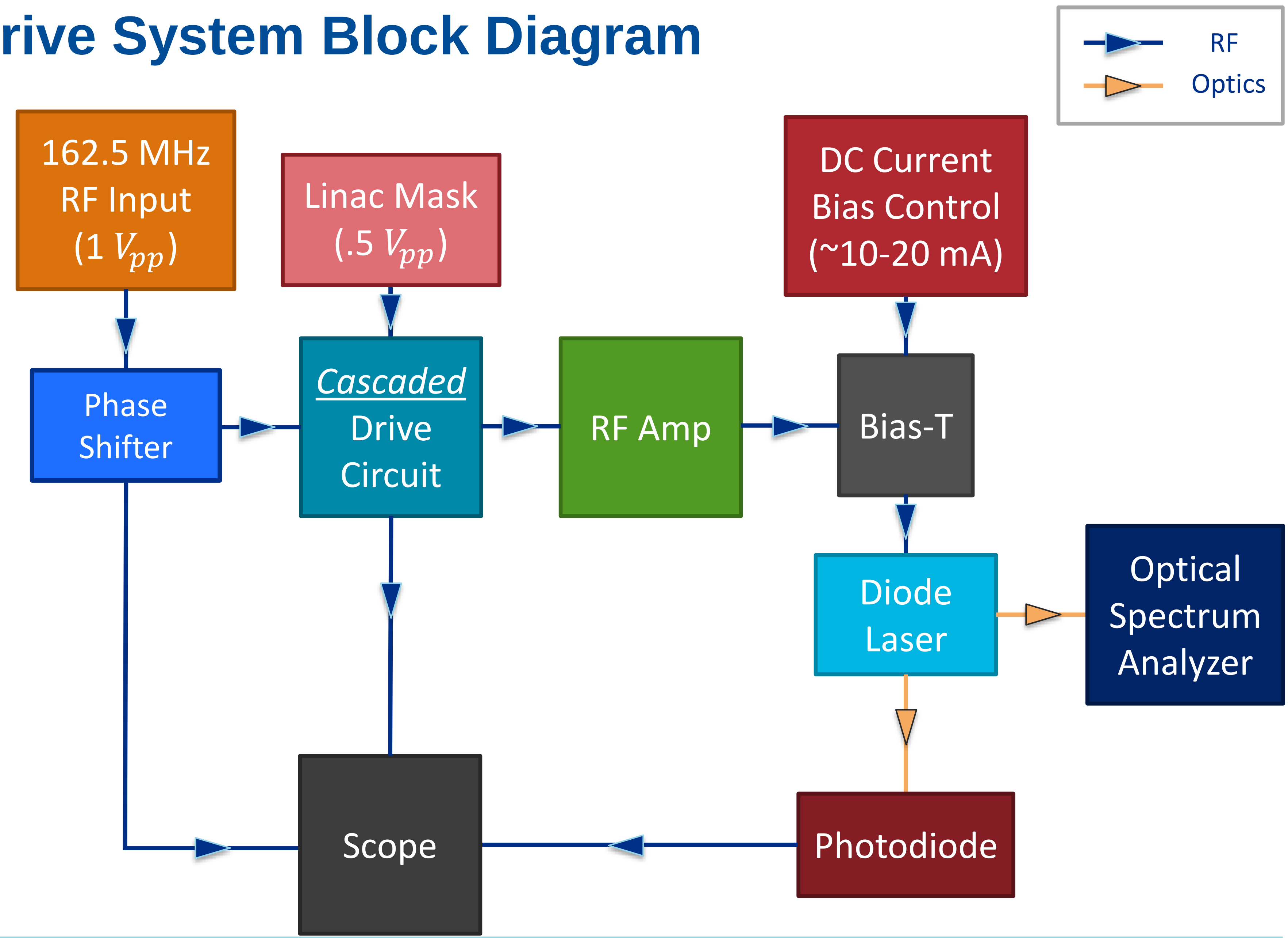
Solution for faster pulses:

- New RF Amplifier
  - DC-12GHz bandwidth
  - Gain 20 dB
- Successful testing completed at BU



H301-1210 – JDS Uniphase Optical Modulator Driver

Drive System Block Diagram



Drive Laser System Conclusions

x/y-spatial measurement previously had timing concerns; we have opted to utilize a gain-switched diode locked to the RF clock. This system meets our tunable 50-200ps pulse widths (FWHM), has phase control external to the laser, and the ability to produce pseudo-random pulse trains.

Advantages

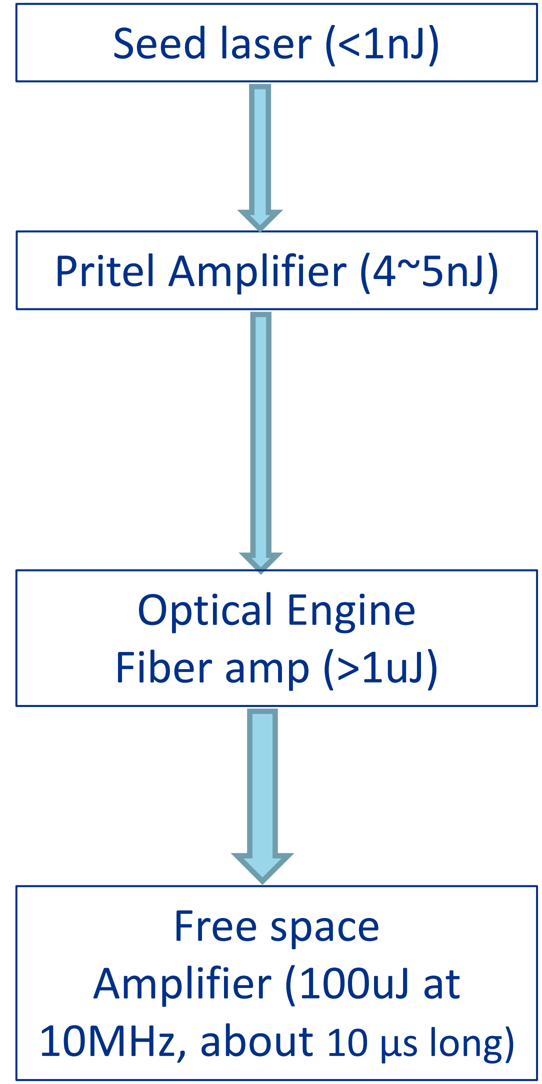
- Cascading drivers allows RF pattern masking
- Pulse width/phase shift/rep-rate controls are decoupled from the laser

Future

- Less downtime and faster replacements
- Easy optimization via driver tunability
- Adaptability any rep-rate changes

Amplification chain

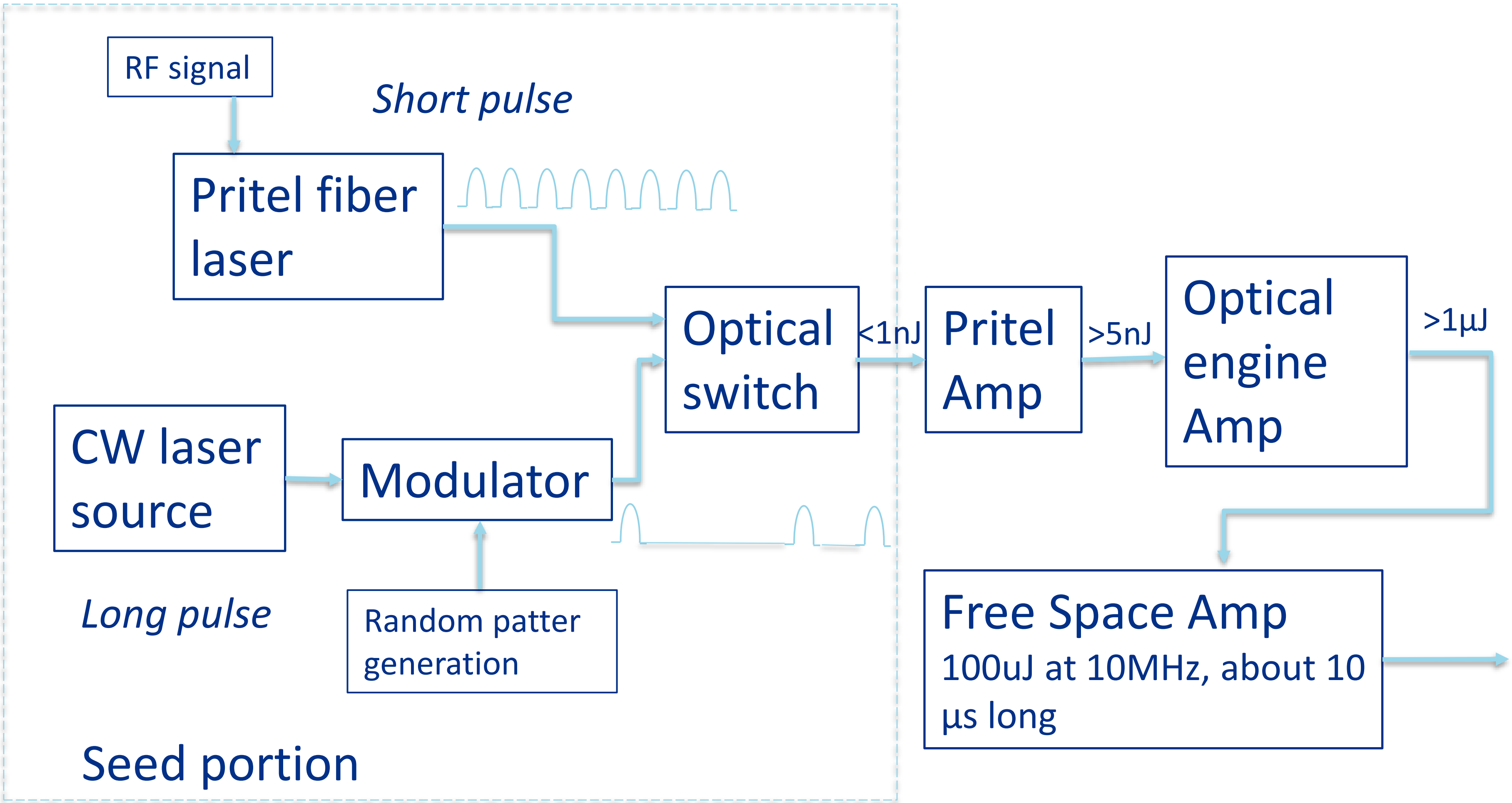
- Fiber portion
  - Pritel
    - Based on the PIPII-IT version again
    - Make it suitable for both seed portion
    - Turn-key
  - Optical engine
    - Why we choose this?
      - Use those state-of-art amplifier to boost the energy
      - A lot of experience with it inside Fermilab
      - Turn-key
      - Multiple system already on order



Amplification Chain

- Free space Portion
  - Northrup Grumann
    - Commercially available
    - Turn-key system
    - Easy for align
    - Been used for multiple system inside Fermilab already
      - Beam strip
      - NML drive laser
    - Upgrade option available to get more power

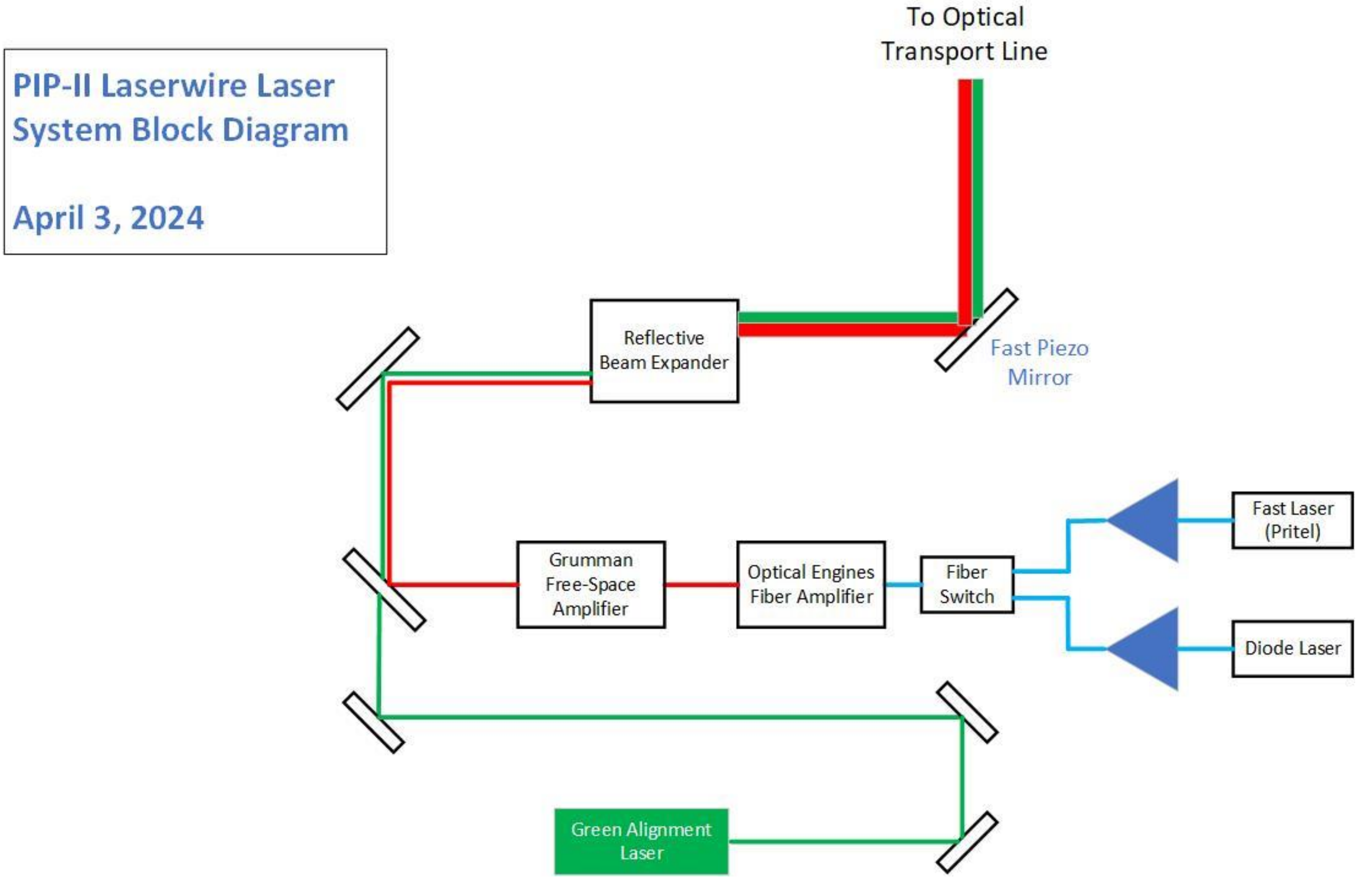
PIPII Laser Diagram



Some consideration for the laser system

- Pros
  - Versatile
  - Be able to deliver high signal noise measurement (see Randy's talk)
  - Cost effective
  - Future upgrade option
- Challenges
  - Need a beam transport structure (See Bob's Talk)
  - Optimizing laser pulse structure (under study)
  - Need some feedback for maintaining beam pointing when travel over long distance (see Randy's talk)

Conceptual Laser Hut Layout



Conclusion

- Based on the comment from PIPII laser wire review we modified our conceptual design for laser system
- New designed system is more versatile
- Newly transport system will be designed and installed
- New design will have higher signal-noise ration than old design
  - Optimizing laser structure to maximize signal