Compact Fiber Laser Approach to Generating 589 nm Laser Guide Stars

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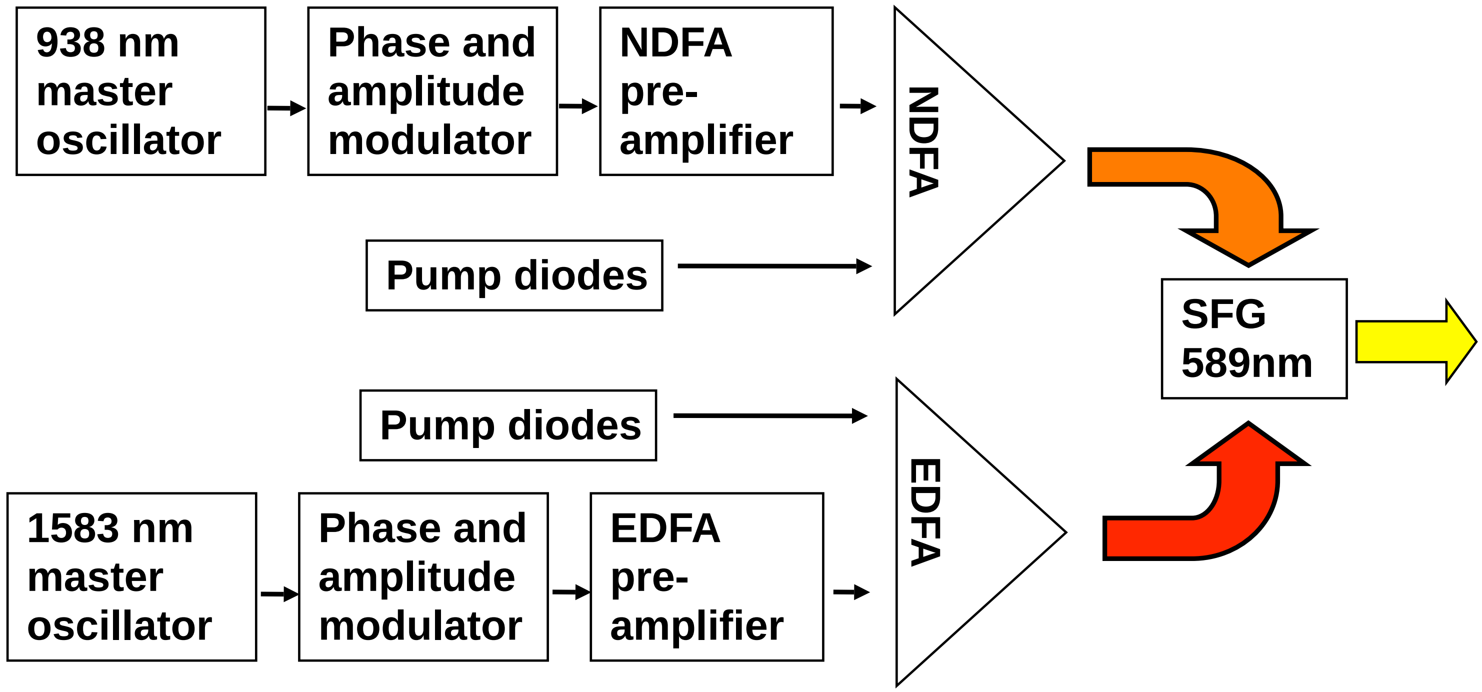
We are developing CW and pulsed fiber lasers for laser guided adaptive optics

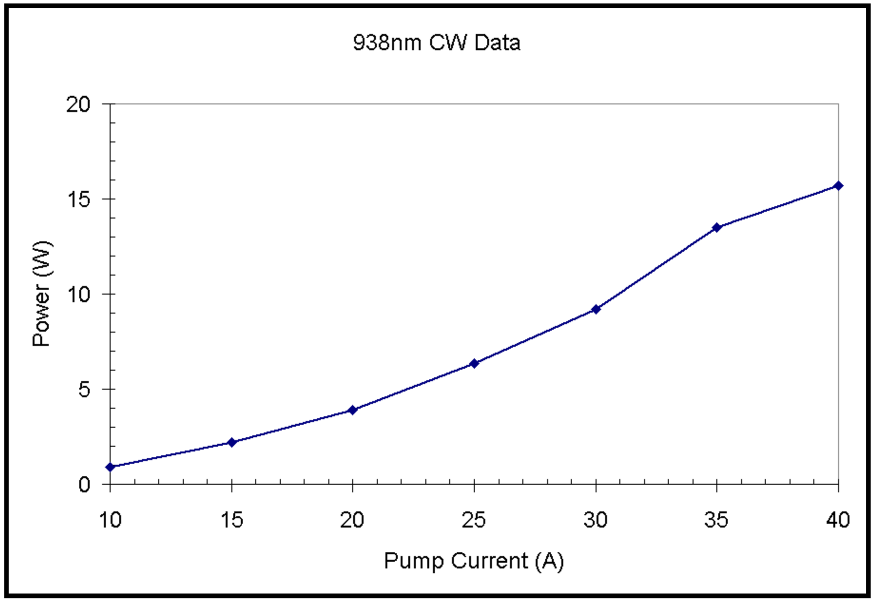


Scaling components to high average power is the main technical challenge

"Synthetic Guide Star Generation," Payne, et.al., US Patent 6,704,331, issued 3/9/04

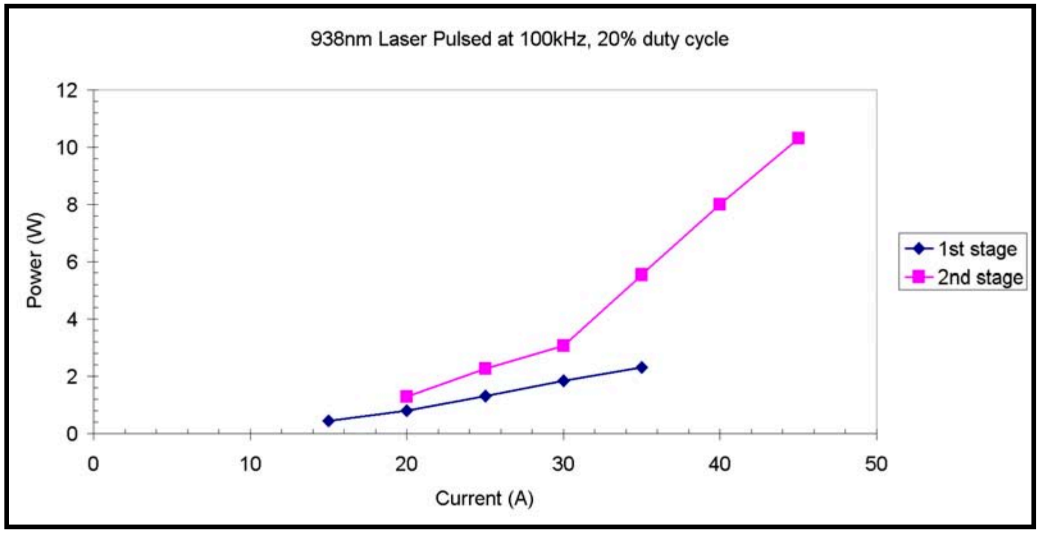
"938 nm fiber laser," Dawson, et.al., US Patent #7038844, issued 5/2/2006

The prototype 938nm laser was a success and we are now packaging it for deployment



938nm laser achievements

- High power operation at room temperature with novel fiber design (US Patent # 7,038,844)
- 15W CW power achieved meeting original targets
- 10W pulsed power achieved at 20% duty cycle
- We have learned enough to proceed to construct a laser we can field in an adaptive optics application on a telescope

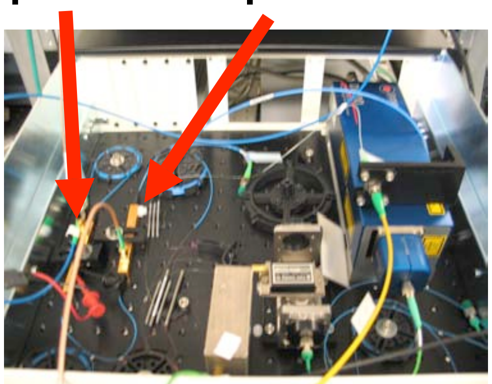


Creating a "turn-key" 938nm laser requires the custom development of a polarization maintaining version of our Nd fiber, matching pump signal combiners and pump diodes. These items had very long lead times (>6 months) and have just now been received.

The 1583nm parts were all purchased commercially

100mW single frequency 1583nm seed laser with PZT tuning

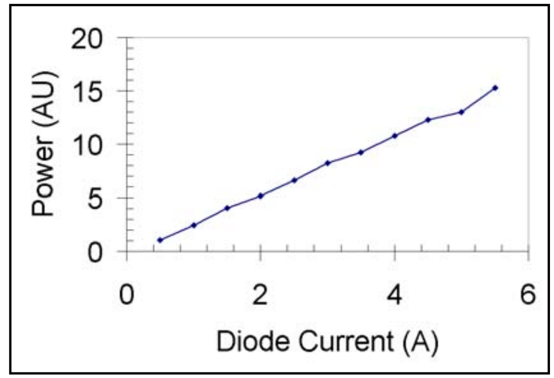
Amplitude and phase modulators



IPG 15W 1583nm amplifier

1583nm laser achievements

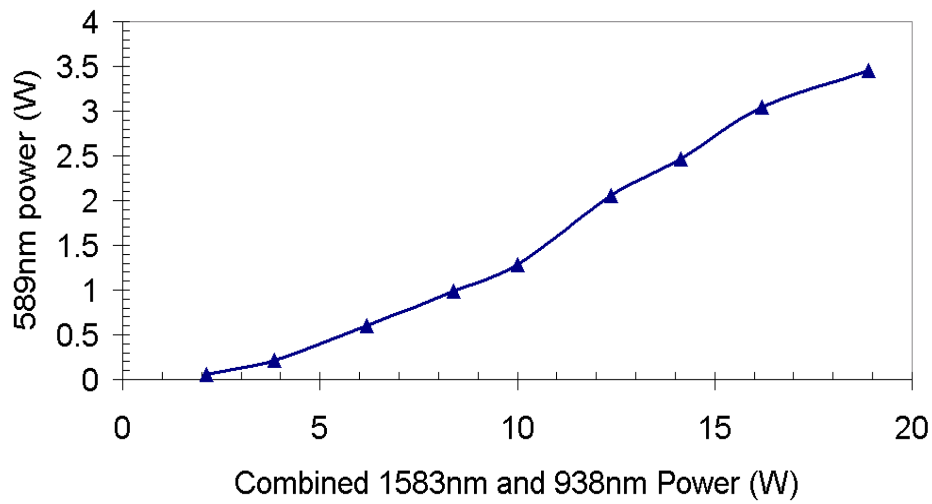
- 15W CW power with no line broadening
- >10W pulsed at 100kHz and 2μs

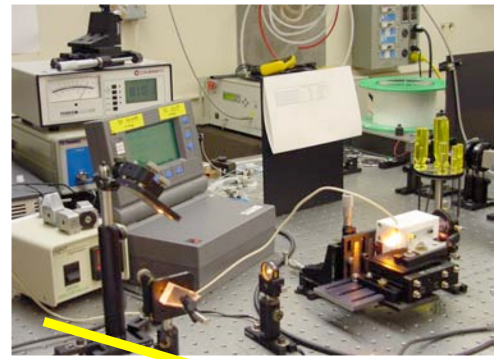


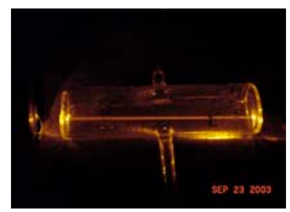
1583nm laser challenges

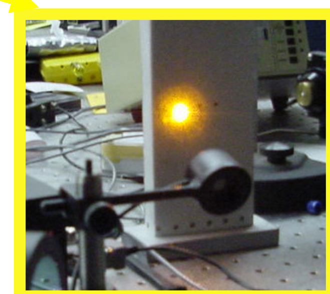
- Spent a lot of first year of operation being repaired particularly the turn-key
- High average power operation at low repetition rates needed for Raleigh gating

Our prototype generated 3.8 W at 589 nm using PPSLT at 100 kHz and 20% duty cycle









589nm achievements

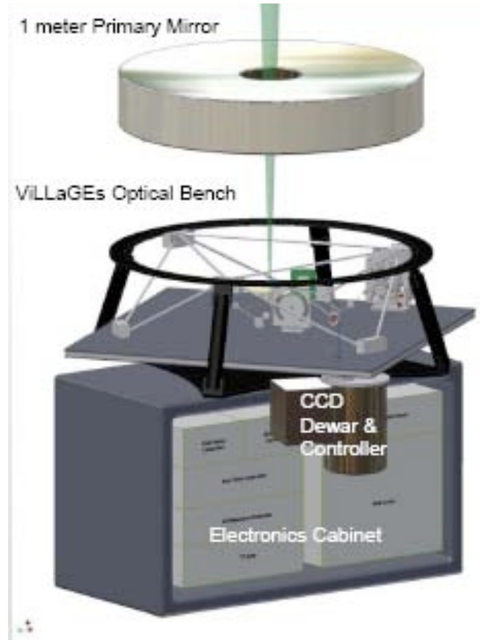
3.8W at 589nm with good beam quality

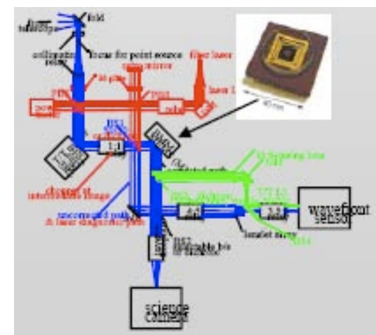
589nm challenges

- **Unpackaged 938nm prototype lacked long term stability at high power**
- **15W 1583nm IPG laser initially spent a lot of time in repair shop**

Conclusion: In hindsight, we spent too much time in the prototype phase of the project pursuing a 10W hero demonstration. Others have now demonstrated the viability of PPSLT at 10W power levels. Once the 1583nm and 938nm lasers have been fully packaged, 10W at 589nm should be achievable.

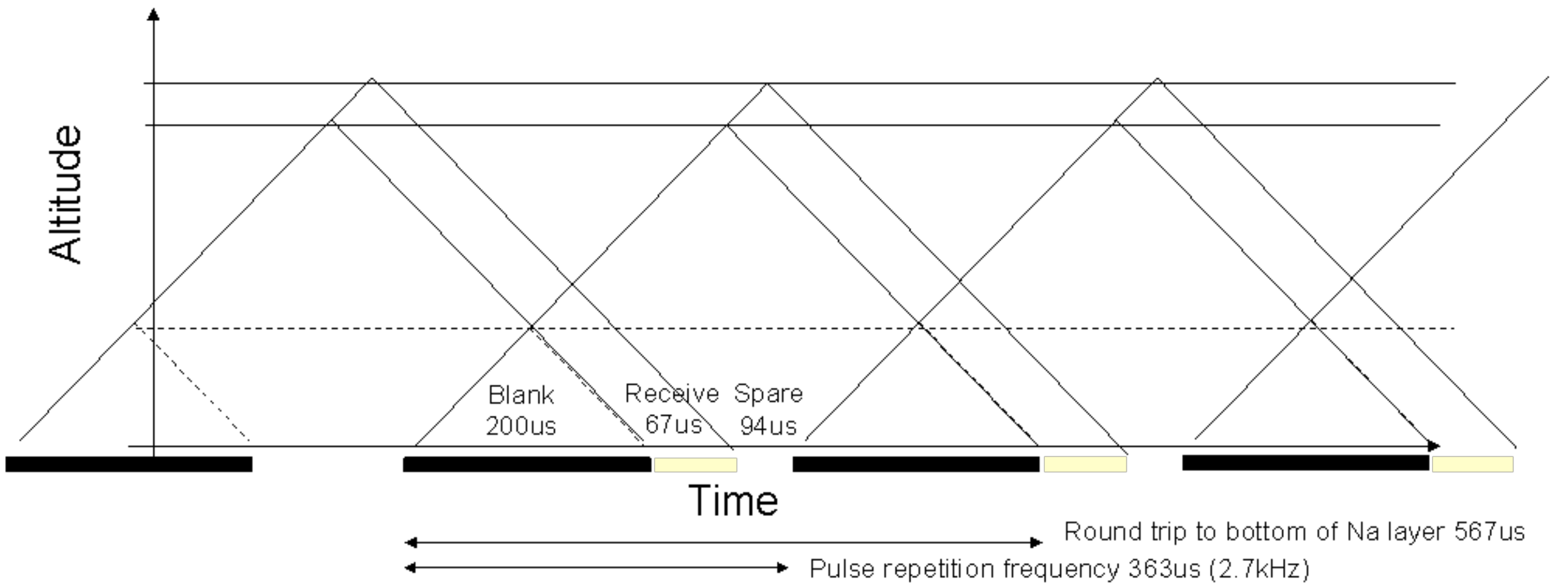
We are now focusing on fielding a system at one of the Lick Observatory telescopes





We are collaborating with Don Gavel and Darren Dillon of UC Santa Cruz (ViLLaGEs) and Bryant Grigsby of Lick Observatory to field the fully engineered version of our laser on the Nickel Telescope as a part of the ViLLaGEs experiment in the summer of 2008. Our AODP sponsors have agreed to this plan of action.

The laser design allows for a programmable pulse format



<u>Rayleigh blanking:</u> ~30μs pulses at 2.7kHz repetition rate scaled by the secant of the azimuthal angle of the telescope ~10% duty cycle

Key challenge: Low repetition rate impacts laser efficiency and square pulse distortion.

<u>Pulse tracking:</u> ~3μs pulses at 14kHz, ~4% duty cycle

Key challenge: low duty cycle, SBS may limit power

Rayleigh blanking will be tested on sky as part of the ViLLaGEs experiment, the pulse tracking format is currently only planned to be tested only in the lab.

The laser design allows for a programmable format

- **Paul Hillman at ARFL has proposed that the high ARFL sodium returns are due the difference between the way single frequency light interacts with the sodium resonance and the way broadband light interacts with that resonance**

- **As the sodium line is Doppler broadened, we can get around the single frequency requirement by requiring the phase modulation lines exceed the rest line width of the sodium D2 transition**
  - **This means the phase modulation sidebands must be at least 200MHz apart**

- **This in turn impacts the design of our phase modulation circuit.**
  - **There are now only 9 peaks inside the 1.5 GHz width of the main D2 line; 0Hz, +/-200MHz, +/-400MHz, +/-600MHz and +/-800MHz**
  - **Since the number is so small, it becomes important to keep the peaks equal in power to maximize the SBS suppression**
  - **This in turn complicates the design of the phase modulation circuit**

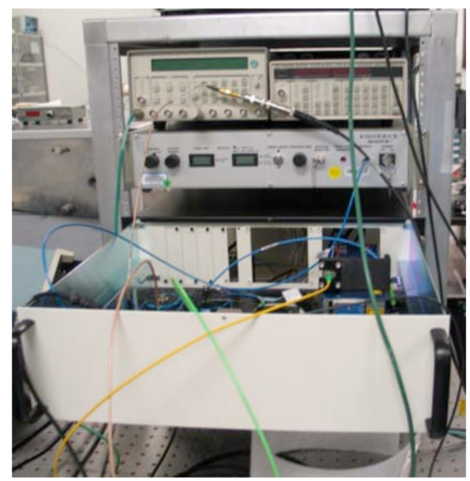
The delivered laser will be rack mounted in the basement of the Nickel telescope at Lick

Racks for fully engineered system: an enclosed sum-frequency breadboard will sit on top of two of the racks and 589nm light will be coupled to a transport fiber for delivery to the launch telescope

Control computer

938nm seed laser control chassis and 1583nm amplifier in lab

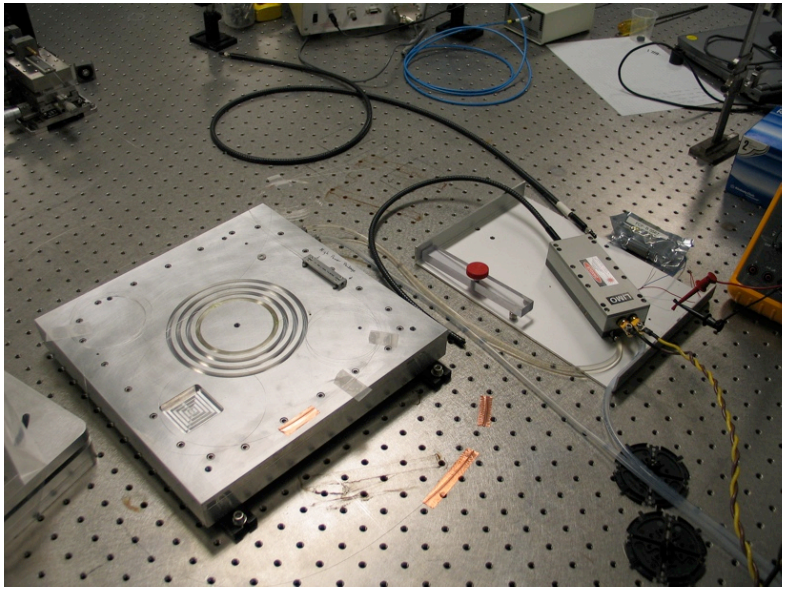
1583nm seed laser and drawer holding 938nm seed laser head as well as phase and amplitude modulators for both lasers

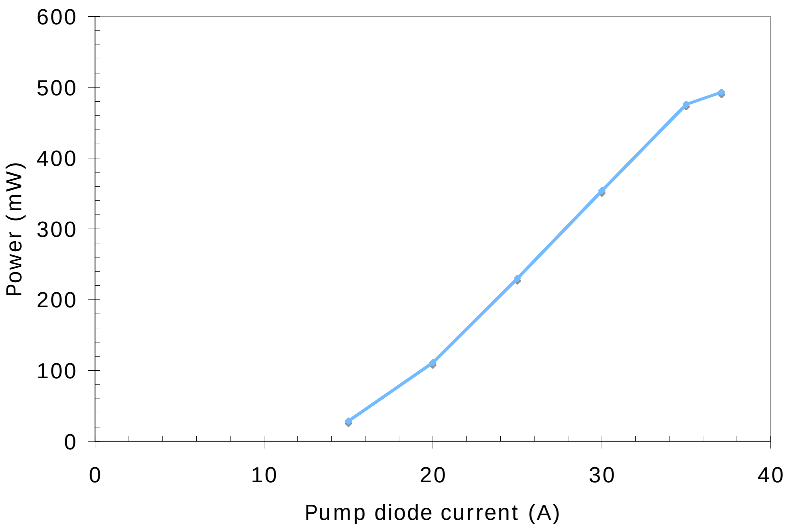


We have plan to package our laser as a full all fiber system to be deployed next summer

Action	Target Completion Date	October	November	December	January	February	March	April	May	June
938nm laser										
808nm pump diode chassis build	10/12/07									
Measure 938nm fiber component characteristics, establish key amplifier parameters	10/19/07									
Design 938nm fiber component module	10/26/07									
Design intra stage rails between fiber amps	10/19/07									
Order isolators and other parts for intra stage amplifiers (include diagnositics ports)	10/26/07		Lead time for parts							
Qualify 938nm seed laser (except final phase modulation circuit)	11/2/07									
Construct amplifiers	12/1/07									
Test and debug amplifiers	12/15/07									
Construct intra stage rails	12/31/07									
938nm amplifier chassis design	11/9/07									
938nm amplifier chassis build	11/28/07									
938nm amplifier full power test	1/15/08									
Test various pulse formats	1/31/08									
Phase modulator circuit										
Mathematical evaluation of requirements	Done									
Circuit design and cost estimate	10/12/07									
Order parts	10/19/07	Lead time for								
Build circuit	11/16/07									
Validate circuit with fabry perot	12/9/07									
Duplicate circuit for 938nm system	12/31/07									
Control system										
Square pulse distortion correction	10/19/07									
1583nm laser full pulsed power test	10/31/07									
Control system development (need to add detail here)	3/31/07									
SFM Breadboard										
SFM Breadboard mechanical design	1/15/08									
SFM breadboard optical + diagnostics design	12/31/07									
Order parts for SFM Breadboard	1/31/08					Lead time for				
Oven design	12/15/07									
Order parts for Oven	12/31/07				Lead time for parts					
Crystal vendor selection	12/15/07									
Order crystals	12/31/07				Lead time for parts					
Receive crystals	2/15/08									
Construct SFM breadboard	3/31/08									
589nm generation and experiments	4/30/08									
Frequency locking	5/31/08									
Stability tests	6/30/08									
Tranfer to Lick	9/30/08									

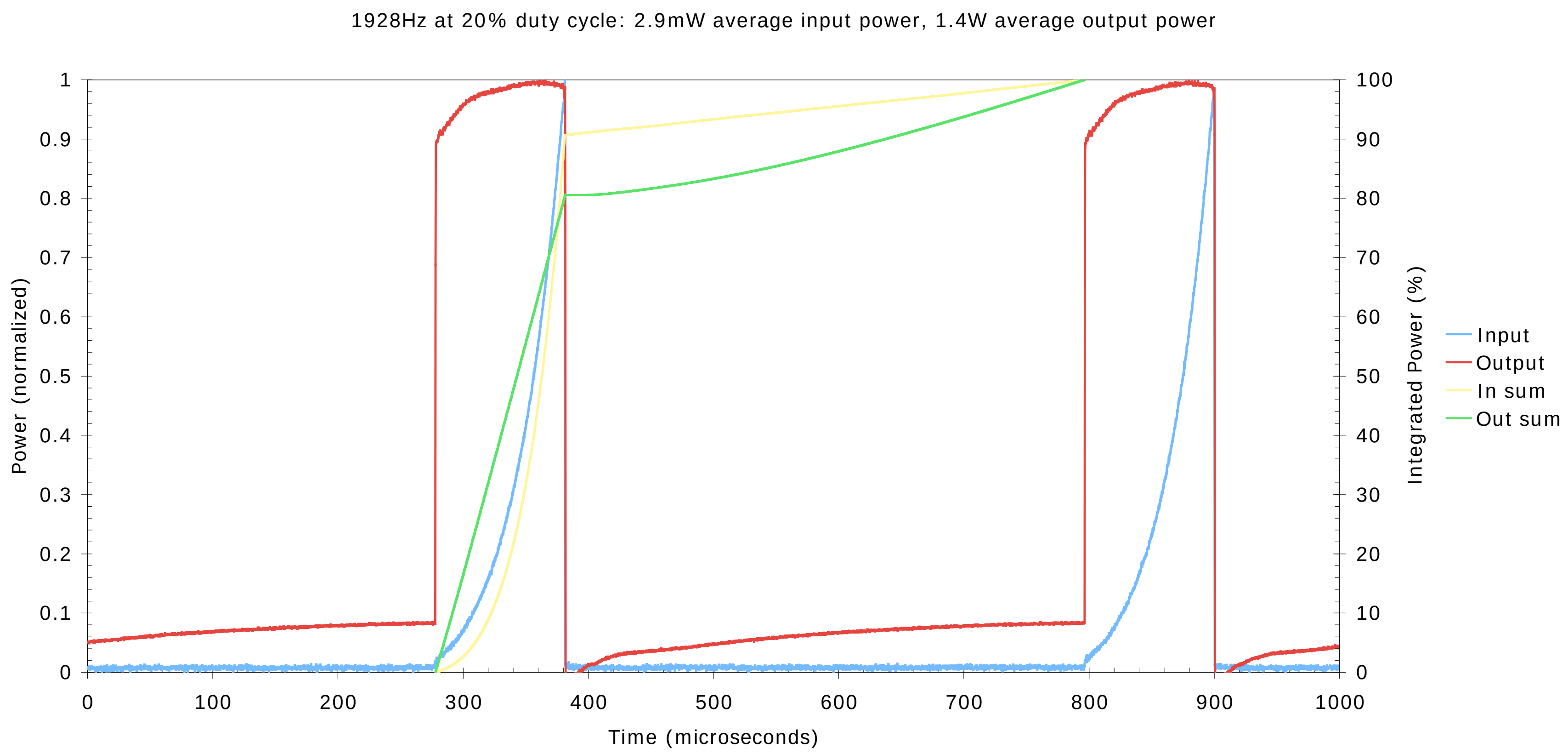
Development of the first stage amplifier is in progress and proceeding well





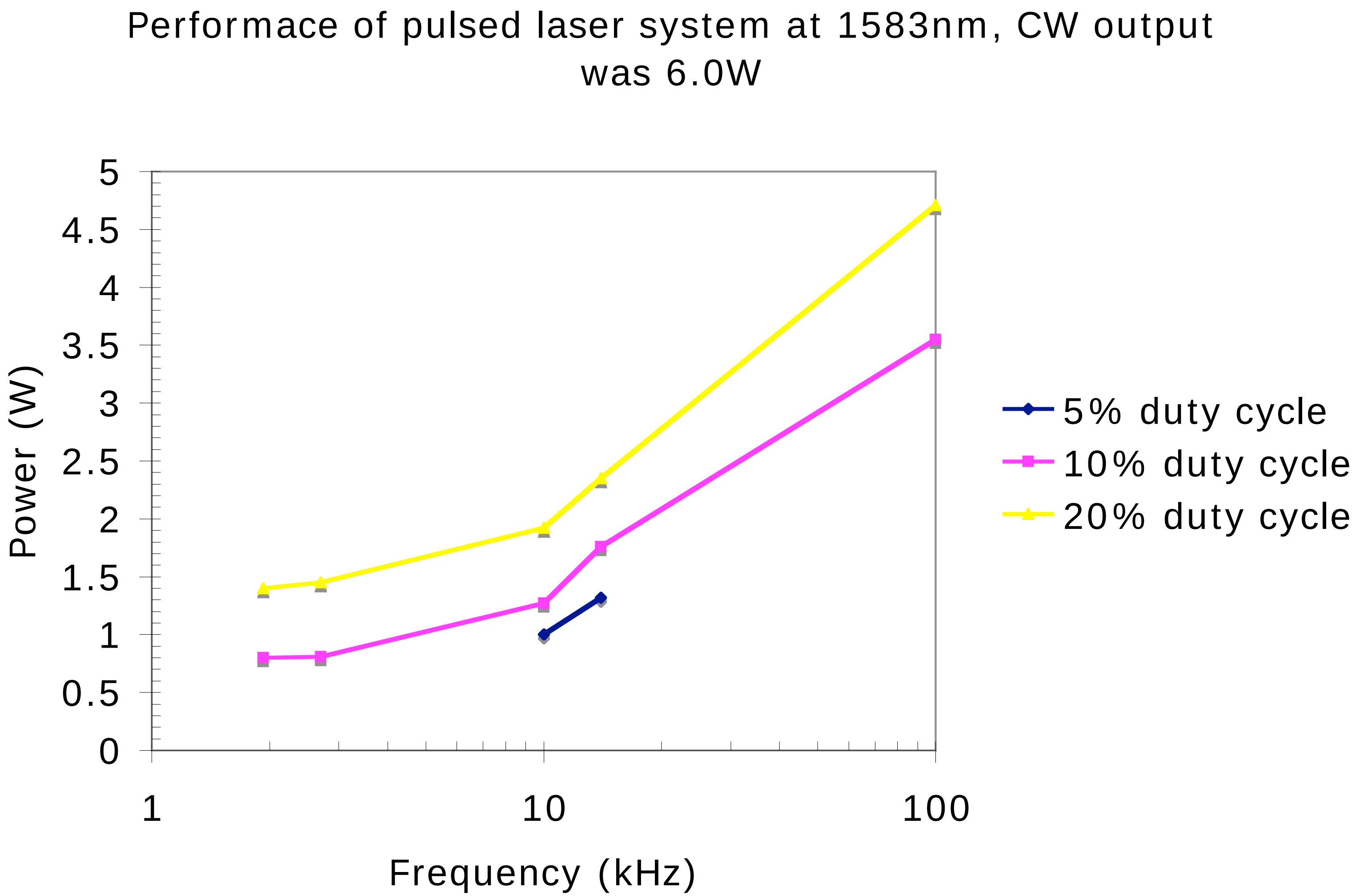
The pump diode emits 25W into a 100 micron diameter, 0.22NA core. 18W makes it through the pump signal combiner. The input signal power for this initial test was 12mW. Measured $M^2<1.2$ limited by stray cladding light. We are planning to proceed by optimizing the amplifier length and coil radius. This amplifier is all PM fiber optics.

We have now demonstrated the capability to correct for square pulse distortion



The square pulse distortion correction algorithm should carry over to the 938 nm system

However, the high gain of the single stage amplifier is causing strong roll-off of power at low repetition rates



1583nm laser status

- The new 15W IPG amplifier has failed again in pulsed operation.
- To achieve good power levels at low repetition rates, we need to split the amplification into several stages anyway.
- I have contacted Nufern about either building a 1583nm pulsed low gain amplifier to our specifications.
- Our go forward plan is to use the current front end along with the old amplifier to get the power level into the 0.5-1W range. We will then insert an isolator, bandpass filter and AOM to remove ASE between pulses. The final stage will have only 10-13dB of gain, which should permit high average power operation at low repetition rates.

Conclusions and key dates

- Our prototype system answered most of the physics questions relating to the fiber laser operation at 938nm and 1583nm. We were successful in reaching the projected power levels in these lasers

- We are constructing a field version of the laser which we plan to deploy at the Nickel telescope at Lick in conjunction with the Villages project next summer

- Current planned milestones
  - All fiber 1583nm laser (working on recovery plan)
  - All fiber 938nm laser (1/31/08)
  - 589nm light from fully engineered system (4/30/08)
  - Control system complete (6/30/08)
  - Transfer to CFAO/Lick (9/30/08)

- Budget issues currently appear OK and we have contingency that should permit us to deal with the 1583nm amplifier issue